Environmental effects of energy production, transformation and consumption in the National Capital Region

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Preface

The deterioration of the air quality particularly in the urban areas, is one of the important environmental concerns in India. The need for incorporating the considerations of air quality into the planning process for such areas is being increasingly realized. The tools to include these considerations in the land use planning are still under development stage.

The project seeks to identify the environmental effects of energy production, transformation and consumption in the National Capital Region, and to develop a procedural framework and modelling tools for prediction of air quality in the region. This study is supported by the Ministry of Environment and Forests. Methodology, corresponding analytical tools, guidelines, standards and appropriate database that will permit land use and transportation planning compatible with acceptable air quality are presented.

Four types of sources of air pollution - industry, power plants, vehicular movement and domestic (cooking stoves) emissions are considered. These sources were categorized as point, line and area sources. The region is divided into grids and the annual emissions of pollutants from each category of source were estimated. Dispersion models for point, line and area sources were developed to predict air quality, using the available data. In this study we have been able to identify the limitations of the current database. These tools can be refined further and with the availability of an adequate database, effectively generate information useful to urban planners and environmental policy makers.

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1. Delhi-Ghaziabad link carries the largest share of the total traffic load (about 25%) in the 12 major corridors under consideration, followed by the Delhi-Faridabad (18%) and Delhi-Noida link (12%). Delhi is a major point of interaction in the region, for both passenger and freight operations. Ghaziabad and Faridabad are other important centres of interaction.
2. Over 26,300 tonnes (t) of CO, 7500 t of HC, 8000 t NO_x, 1250 t of SO_2, 230 t of TSP and 10 t of Pb are released annually in the 12 links together. CO , HC and NO_x are the pollutants of concern. CO (86%) and HC(87%) are mainly contributed by the passenger modes of transport. Diesel driven buses and trucks emit NO_x and SO_2 and TSP (59%, 66%, and 69%) and passenger vehicles are responsible for Pb emission.
3. Emission rate is highest for corridors Delhi-Ghaziabad (Corridor 1), followed by Delhi-Faridabad (Corridor 3). Other important corridors in the order of importance are Delhi-Noida (Corridor 2), Delhi-Gurgaon (Corridor 5) and Ghaziabad-Meerut (Corridor 8).
4. Growth rate of vehicles was around 10% per annum between 1970-71 and 1990-91. Two-wheelers have grown at the rate of 13% per annum, cars with 7% as compared to public transport buses at 7%. With this trend of vehicle growth, congestion on roads has increased,traffic speeds have reduced, resulting in the fall in the energy efficiency and increase in the pollution levels.
5. Intra-city vehicular movement in Delhi release over 1,86,000 t of CO, 77230 t of HC. and 1,74,000 t of NO_x. CO, HC and NO_x are important pollutants. Petrol driven vehicles are the major contributors of CO (96.5%) and HC (96.7%), whereas SO_2 (86%) and NO_x (71%) are mainly contributed by diesel driven vehicles.Two-wheelers and cars are the main sources of CO and HC emissions, while buses are the major source of NO_x, SO_2 and TSP emissions.
6. Grid-wise annual emissions from transport sector are high in grids D4 (Delhi), D5 (Delhi, Ghaziabad, Loni), F5 (Palwal), E5 (Faridabad) and G5 (Hodal). This is because of the large number of high emission rate corridors passing through these grids.

Domestic sector

1. Grids D4 (Delhi), D5 (part of Delhi, Ghaziabad and Loni), C6 (Meerut, Modinagar, etc.), E5 (Faridabad), A3 (Panipat) and C2 (Rohtak) have high urban population levels. The total emission from the domestic sector for both rural and urban areas are 5760 t of CO, 37456 t of HC, 643 t of SO_2, 281 t of NO_x. CO and TSP have high emission levels. For grids B, C, D, E (5,6,7) high levels of domestic emissions from the rural sector are observed. The grids with highest levels of urban domestic emissions are D4 (Delhi), D5 (parts of Delhi, Ghaziabad and Loni), C6 (Meerut), E5 (Faridabad), C2 (Rohtak), H2 (Alwar) and A3 (Panipat).

Industry

1. The major polluting industries in the sub-region of Delhi are Chemicals (24%), Foundry (47%), and Textiles (10%). Coal and fuel oil are the main fuels used. Stone crushing activity is the major source of TSP pollution in the Najafgarh Road, Wazirpur, Motinagar, Kirti Nagar, Lawrence Road of UT of Delhi. Ghaziabad accounts for 60% of all the industries of UP sub-region; Meerut 30%; and Bulandshahr 10%. The concentration of industries in Haryana sub-region is in Faridabad, Karnal and Sonipat. Coal is the most commonly used fuel. Alwar and Behror are important industrial centres of Rajasthan sub-region.
2. The break-up for total emission from the industrial sector is: 62207 t of TSP, 73447 t of CO, 25048 t of SO_2, 13294 t of NO_x and 18058 t of HC. CO and TSP are pollutants of concern in most of the industrial areas and their high emission levels is attributed to inefficient burning of coal and furnace oil. Grids where the industrial emissions are substantial are A4 (Panipat), D5 (part of Delhi, Ghaziabad and Loni), C4 (Sonipat, part of Delhi and Baghpat), E5 (Faridabad), D4 (Delhi).
3. CO is the major pollutant (257 t per annum) in the Okhla Industrial Area (Grid D5), followed by HC. Inefficient burning of coal and furnace oil results in high levels of CO.
4. In Shahdara (Grid D5), CO (960 t per annum) followed by SO_2 (300 t per annum) are of prime concern. Stone crushers and brick kilns are responsible for high levels of TSP in Najafgarh Road, Lawrence Road , Wazirpur, Kirti Nagar, DLF and Motinagar. The amount of SO_2 released in Kirti Nagar Industrial Area is a serious concern.
5. CO is the single largest pollutant in Ghaziabad because of coal combustion. Burning of rice husk contributes significant amounts to TSP pollution in Bulandshahr. CO emissions, followed by TSP emissions are largest in Meerut.

Power sector

1. 3178 t of TSP, 61920 t of SO_2, 8150 t of CO, 4071 t of HC and 61106 t of NO_x are emitted annually by power plants. SO_2 and NO_x levels are significantly high because of uncontrolled release of pollutants.

Annual emissions

1. The pollution loading of TSP, CO, SO_2, NO_x and HC from industry, transport and domestic sectors aggregated together are in the order of 68300 t, 151129 t, 27508 t, 25479 t and 29557 t annually. Industrial sector accounts for a major share of the emissions, particularly TSP and SO_2 (96%), followed by the transport sector. NO_x and HC are equally shared by industry and transportation sectors. A substantial amount of CO is generated by the domestic sector. The grids which experience high emission levels in the order of decreasing significance is given in Table 1. The location of these grids are given in Table 2. Industrial sector in general, contributes a substantial share of all pollutants in all the grids. Meteorology is an important variable that influence the ground level concentration. The meteorological data is very inadequate in the region.

Table 1. Sensitive grids in decreasing order of importance

Pollutant	1	2	3	4	5
TSP	D4	D5	D3	A4	C4
CO	D5	A4	C4	D5	E5
SO_2	D5	C4	A4	E5	D3
NO_x	C4	D5	A4	E5	C3
HC	D5	A4	C4	E5	C1

Table 2. Location of grids

Grid	Location
A4	Panipat
C1	Meham, Kalaria, part of Rohtak
C3	Part of Sonipat
C4	Baghpat, parts of Sonipat and Delhi
D3	Bahadurgarh, part of Delhi
D4	Delhi
D5	Part of Delhi, Ghaziabad and Loni
E5	Faridabad

Concentrations

Line source

1. The eight-hour averaging concentration levels across the corridors show that corridors 1, 3, 2, 7 and 4 experience high concentration levels of CO and HC, resultant of large passenger vehicular movement in these corridors. Corridors 1, 2, 3 and 8 have high TSP, SO_2 and No_x levels owing to large fleet of diesel driven vehicles in these corridors. The concentration levels of NO_x (150 g/m³) exceed the permissible standards in the Delhi-Ghaziabad corridor. The concentration levels of HC are also close to the standards. Wind speed is a crucial factor in influencing the concentration levels. Lower wind speeds produce higher concentration.

Area source

1. The five high polluting grids identified on the basis of domestic, industrial and intra-city transport emissions are given in Table 3. The location of these grids are given in Table 4. The concentration levels of TSP exceeds the standards in grids D4 and D5. The concentration of CO is close to the permissible standards. SO_2 exceeds the standards in grids D4, D5, C4, and A4 whereas NO_x exceeds in D4, D5 and C4.

Table 3. Sensitive grids

Pollutant	1	2	3	4	5
TSP	D4	D5	D3	A4	C4
CO	D4	D5	A4	C4	E5
SO_2	D5	C4	A4	D4	E5
NO_x	D4	D5	C4	A4	E5
HC	D4	D5	A4	C4	E5

Table 4. Location of grids

Grid	Location
A4	Panipat
C4	Baghpat, parts of Sonipat and Delhi
D3	Bahadurgarh, part of Delhi
D4	Delhi
D5	Part of Delhi, Ghaziabad and Loni
E5	Faridabad

Point source

1. Stable conditions give rise to very high plume rise and consequently very low ground level concentrations (GLCs). Unstable conditions induce moderate to higher levels of GLCs. The levels of SO_2 and NO_x are high vis-a-vis other pollutants. Higher wind speeds produce maximum GLCs at a distance of approximately 4 km.
2. The power plants in Panipat, Delhi and Faridabad produce concentrations in the range of 35-55 g. m^{-3}.Though the source strength of Badarpur power plant is very high vis a vis Panipat and Delhi units, the GLC due to Badarpur plant is observed to be less than that of plants at Panipat and Delhi. This is due to high stack height of power plant at Badarpur.
3. The concentrations under worst atmospheric conditions produce very high concentration levels. The maximum concentrations due to Panipat plant under fumigation conditions were observed as high as 79 g/m^3 and 35 g/m^3 under trapping conditions. Maximum GLC under fumigation conditions occurs at a distance of less than one km and under trapping maximum GLC occurs within the range of 3-4 km from the stack.
4. Concentration beyond 10 km is insignificant under all the conditions. Thus, the grids A4 (Panipat), D4 (Delhi), D5 (Parts of Delhi, Ghaziabad and Loni), E5 (Faridabad) and D6 (Dadri) will experience high levels of concentrations due to power generation.

Chapter 1

Introduction

The deterioration in the air quality of urban areas is one of the major environmental concerns in the country today Of all the anthropogenic sources, the contribution of energy related activities to the total emissions of pollutants in the atmosphere is probably the highest.

Patterns of land use and their accompanying activities are major determinants of the type and amount of air pollution generated over a region. Historically, specification of land use has been relatively insensitive to air quality considerations, but recent concern for environmental quality has fostered attempts to improve air quality through direct control of the sources of emissions. The current focus of these attempts is on emission control and more efficient fuel utilization. However, this type of approach does not by itself address the problem of planning for long-term air quality.

The specification of land use is one of the means to maintain air quality levels. Land-use activities including specific emission sources, can be related to the rate of pollution discharge. Characterization of the types and extent of residential, commercial, industrial and transportation activities that are consistent with air quality criteria, can form the basis for generating urban configurations, which are compatible with acceptable levels of pollution.

In order to maintain desirable and realistic levels of pollution, it is necessary to define and implement within the planning process a methodology, corresponding analytical tools, guidelines and standards, and an appropriate database that will permit land use and transportation planning compatible with acceptable air quality levels. This method of planning for air quality will provide direction for planning new development. Though air quality considerations pose a limit on the freedom to designate the extent, type and sites of land use, it is imperative that air quality impacts of development are considered simultaneously with other planning criteria in designing future land use activities. However, the efforts to develop tools to aid urban planners to incorporate environmental concerns in land use planning have been limited.

This study assesses the effects of energy transformations on the air quality within a quantitative framework in a region. Such studies are particularly important in setting environmental standards directed at ensuring an optimal level of pollution control in a specific region. The National Capital Region (NCR) was selected for applying the methodology developed in this study.

The NCR was demarcated for the purpose of developing a region around the Union Territory (UT) of Delhi to achieve balanced growth. The main objective of the regional plan is to restrict the share of Delhi's sub-regional population to 11.2 million as against the projected 13.2 million. While restricting the growth of Delhi it is important to ensure that the difference in the growth is controlled within a region, in a planned manner. It is also necessary that the resultant extra growth in the region outside Delhi is of such a nature that it will have an overall effect in the entire region stimulating its regulated and orderly growth in and around the centres selected for development. This region encompasses Delhi UT as its core and parts of Haryana, Rajasthan and Uttar Pradesh states. It accommodated a total population of 19.2 million in 1981. Of this, Uttar Pradesh sub-region accounted for a share of 36% followed by Delhi UT (32%), Haryana (26%) and Rajasthan (6%). The total area of NCR is 30,242 km^2, of which Haryana accounts for 44% followed by UP (36%), Rajasthan (15%) and Delhi UT (5%).

The specific objectives of this study were:

- To identify the sources of air pollution in the NCR and to compile an inventory of sources in different categories (line, point, area).
- To estimate the emissions of pollutants (TSP, CO, HC, NO_x, SO_2, Pb) from various sources in different zones, and to estimate the strength of each category of sources of the pollutants.
- To develop models to predict the concentrations of various pollutants resulting from different sources in selected areas of the NCR and to identify areas with high levels of air pollution.

1.1 Approach

The air quality in a region depends upon: pollution source characteristics, the ability of the atmosphere to disperse, transform and remove pollution loadings generated by energy related activities. The capacity of an air basin over a region to disperse transform and remove atmospheric pollutants depends upon a variety of factors, including the amount and type of pollutants emitted and meteorological and topographical characteristics of the region. To examine the air quality in the NCR the following methodology was adopted in this study.

1. Division of region into grids

The formation of grids was undertaken after examining the data on industries as these are expected to be the major contributors to the emissions. The data on air polluting industries has following limitations:

(i) the listing of air polluting industries is not exhaustive,

(ii) the data for industries in different regions are for different years, and

(iii) the location of many of the surveyed industries was not available.

Hence, the grid size in this study is arbitrarily fixed as 24 x 24 km. These dimensions are large for an air quality study but can be used to identify vulnerable areas in the region. These vulnerable areas can be then studied in detail to examine the options for future activities.

2. Establish the source inventory

Sources are generally referred to as point, line and area sources. Point sources represent major, identifiable sources within a region, such as power plants, Line sources represent emissions from motor vehicles along principal highways. Area sources represent cluster of small industrial sources such as industrial pockets, domestic emissions and intra-city transport emissions. The point, line and area sources are mapped in each of the grids of the region. The technical data for each power plant and its location are compiled. The major transport corridors with the volume of traffic classified by goods, buses and passenger vehicles are considered. The intra-city vehicular movement was computed based on the secondary data on vehicle registration. Population, both rural and urban, was mapped in each of the grids. The inventory of air polluting industries in the NCR with the data on type of industry, fuel use, stack height, type of boiler, etc. were compiled for each of the grids.

3. Estimation of emissions from different categories of sources and apportionment to each grid

Polluting source characteristics include the quantity of emission and the physical location and configuration of the sources. Source emissions are in turn determined by type and amount of fuel used, emission factors, process rate, source control, etc. Emission factors are compiled from the secondary sources classified by the end-use, type of fuel used and the types of boiler in the industry and power plants.

4. Evaluate the air quality using air pollution dispersion models, taking into consideration different sets of meteorological conditions

The pollution emission from different sources (point, line and area) is translated into concentration levels using air pollution dispersion models. Gaussian plume models for point, line and area sources were developed on a computer PC-AT, to arrive at both short-term and long-term concentration levels.

5. Identify the sensitive zones (grids), and comparison with the air quality standards

In order to define the tolerance of the planning area towards receiving additional pollution, sensitive zones need to be identified and avoided from further degradation. The concentration levels observed in each of the grids and in corridors are compared with the air quality standards, to arrive at the sensitive zones.

The main advantage of this study is the availability of a set of models and a framework that is intended to provide information to urban and regional planners, and environmental policy makers that will facilitate the incorporation of air quality considerations into the planning process.

In Chapter 2, the emission factors for different pollutants due to all types of vehicles, cooking stoves, boilers used in industries and power plants are summarized. Chapter 3 provides the available data on transportation, domestic fuel consumption, industries and power plants. The method of estimation of annual emissions of different pollutants due to different sources is explained in Chapter 4. The sources contributing to high levels of emissions in different regions are identified. The status of meteorological data and air quality data is given in Chapter 5 and 6 respectively. Chapter 7 outlines the basic models and Chapter 8 illustrates their uses. Finally, based on the findings of this study, activities needed to generate information for urban planners are listed in recommendations.

Chapter 2

Emission factors

An emission factor (EF) is defined as the ratio of the rate at which a pollutant is released into the atmosphere as a result of some activity, such as domestic fuel combustion or industrial production, to the rate of that activity. It is a composite of all the sub processes comprising major processes, and does not take into account the matter of start-up/shut-down or batch operations. The emission factors can be determined by detailed source testing involving many measurements or by engineering analysis of process material balances.

Emission factors depend on various parameters involved in the process. The important parameters among these are: (a) type of fuel and its composition. Because a particular fuel can have different composition, it is convenient to express the emission factors in terms of variable parameters. For example the composition of coal varies with respect to ash (A) and sulphur (S) content. Hence, the emission factor of coal must be expressed in terms of these two parameters (A and S); (b) type of burner/furnace involved in the process; and (c) the process involved.

In this chapter, emission factors for different pollutants due to all types of vehicles, cooking stoves using various fuels, and boilers used in industries and power plants are summarized The pollutants that are considered in this study are Carbon monoxide (CO), Hydrocarbons (HC), Nitrogen oxides (NO_x), Sulphur dioxide (SO_2), Lead (Pb) and Total suspended particulates (TSP).

2.1 Transportation sector

Automobile exhaust contributes invisible carbon monoxide, unburnt hydrocarbons, oxides of sulphur and nitrogen, lead and visible smoke. Data on emission factors are normally expressed in grams of pollutant per kg of fuel used for various types of vehicles. Table 2.1.1 shows the data for trucks and buses using diesel.

Table 2.1.1. Emission factors of diesel vehicles (g/kg of fuel)

Mode	CO	HC	NO_x	TSP
Trucks/Buses	22.8	8.83	43.1	1.43

Source: IIP, 1985

Note: The driving cycle adopted by IIP for measuring the emission factors is termed as four-mode cycle and consists of four modes of operations - idling, acceleration, cruising, and deceleration.

The data on fuel efficiency i.e. kilometres per litre of fuel for different vehicles were compiled from different sources and are summarized in Table 2.1.2. These data are combined with the data available on emission factors and Table 2.1.3 is compiled to provides basic data for estimation of emissions.

Table 2.1.2. Fuel efficiency by mode

Mode	Fuel type	Fuel efficiency (km/litre)
Two-wheelers	Petrol	44.4
Cars	Petrol	10.9
Three-wheelers	Petrol	20
Buses	Diesel	
suburban		3.3
urban		4.3
Trucks	Diesel	5.5
Light commercial vehicles	Diesel	10

Source: GOI, 1989

Table 2.1.3. Emission factors for different vehicles (g/km)

Mode	CO	HC	NO_x	SO_2	Pb	TSP
Two-wheelers	8.3	5.18	-	0.013	0.0028	-
Cars	24.03	3.57	1.57	0.053	0.0116	-
Three-wheelers	12.25	7.65	-	0.029	0.0063	-
Buses						
suburban	5.87	2.27	11.1	1.93	-	0.37
urban	4.51	1.75	8.52	1.48	-	0.28
Trucks	3.52	1.36	6.66	1.16	-	0.22
Light commercial vehicles	1.3	0.5	2.5	0.4	-	0.1

Source: IIP, 1985

Assumptions

Following assumptions were used to estimate the emission factors of SO_2 and Pb.

SO_2 emissions: In petrol, the concentration of sulphur ranges from 0.05 to 0.1% (w/w). For the calculation of SO_2 emissions, an average sulphur concentration in gasoline of 0.08% has been taken. Further, it is assumed that all the sulphur gets converted to SO_2 and is exhausted through the tail pipe. For diesel fuel, the concentration of sulphur is approximately 0.75% (w/w) and all the sulphur present in diesel fuel gets converted into SO_2.

Pb emissions: The petrol from Mathura refinery supplied to Delhi and other areas in NCR is assumed to contain 0.18 g/litre of lead. The specific gravity of petrol is taken to be 0.72. An assumption is made that, about 70% lead supplied to the engine is released from the tail pipe, the rest being deposited in the engine combustion chamber and exhaust system.

In actual driving conditions, the typical driving cycle is rarely feasible. The emissions of a pollutant from a vehicle depend on its speed, age and road conditions. However, for this study we have assumed the emission factors as given in Table 2.1.3.

2.2 Domestic sector

The major fuels used for cooking are fuelwood, crop residues and dung-cakes - predominantly used in rural areas - and kerosene, coke and liquid petroleum gas (LPG) mainly used in urban settlements. The critical pollutants that are released from

biofuels are CO and TSP, whereas LPG stoves release substantial amount of NO_x. The data on emission factors for various fuel types are presented in Table 2.2.1.

Table 2.2.1. Emission factors for cookstoves using different fuels (g/kg)

Pollutant	Kerosene	LPG*	Coke*	Fuelwood	Dung-cake	Crop residue
TSP	2.8	-	20	1.9	4.9	3
CO	41	0.02	17	17	31	27
SO_2	-	-	-	-	-	-
NO_x	-	5.25	-	-	-	-

Source:* Sittig, 1975
TEDDY, 1989

2.3 Industry and power plants

The emission factors recommended by World Health Organization (WHO) and Environmental Protection Agency (EPA) have been used for estimation of emissions from power plants and industries. These emission factors are expressed in terms of variable parameters such as ash and sulphur content of fuel, types of boiler used, etc. The appropriate values of A and S, and types of burners involved in the process have been taken into account while calculating the gross emission in NCR. The emission factors used in this study are given in Table 2.3.1.

Power plants use boilers having thermal input of more than 1000 x 10^6 Btu per hour to generate electricity. These boilers are either tangential or spreader stroke in nature. Coal and fuel oil are the common fuels used in the boiler. Though fuel oil is used during the start up of the boiler, its contribution to the total emission is negligible, and hence it has not been taken into account.

Table 2.3.1. Emission factors for boilers used in industry and power plants (g/kg)

Fuel	TSP	SO_2	CO	HC	NO_x
Coal Bituminous (without control equipment)					
a) Hand-fired	10	19S	45	10	1.5
b) Under feed stroker (10^6 Btu/h heat input)	1A	19S	5	1.5	3
c) Spreader stroker (10-100)x10^6 Btu/h heat input: for power plants)	6.5A	19S	1	0.5	7.5

A - Ash content in wt percentage

S - Sulphur content in the fuel Assumed value for coal 0.4%

Table 2.3.2. Emission factors for boilers used in industry and power plants (g/litre)

Fuel	TSP	SO_2	CO	HC	NO_x
Fuel oil					
a) Residual oil					
i) Power plant boiler	1.25S+0.38	19.25S	0.63	0.12	Tangentially fired - 6.25 Others -
ii) Industrial and commercial boiler	1.25S+0.38	19.25S	0.63	0.12	12.6 7.5
b) Distillate oil for industrial and commercial boiler	0.25	17.25S	0.63	0.12-0.14	2.7-2.8

S - Sulphur content in the fuel Assumed value for furnace oil 0.3%

Table 2.3.3. Emission factors for boilers used in industry and power plants (kg/$10^6 m^3$)

Fuel	TSP	SO_2	CO	HC	NO_x
Natural Gas					
a) Power plant	80-240	9.6	[illegible]	[illegible] (as CH_4)	Tangentially Boiler - 4800 Others - 11,200
b) Industrial boiler	80-240	9.6	272	48	1920-3680

Table 2.3.4. Emission factors for boilers used in industry and power plants (g/litre)

Fuel	TSP	SO_2	CO	HC	NO_x
LPG					
a) Industrial furnace					
i) Butane	0.22	0.01S	0.19	0.036	1.45
ii) Propane	0.20	0.01S	0.18	0.036	1.35
b) Domestic and commercial furnace					
i) Butane	0.23	0.01S	0.24	0.096	1-1.5
ii) Propane	0.22	0.01S	0.23	0.089	0.8-1.3[1]

[1] - Lower value for domestic and higher value for commercial

S - Sulphur content in the fuel. Assumed value for LDO 0.2%

Table 2.3.5 Emission factors for boilers used in industry and power plants (g/litre)

Fuel	TSP	SO_2	CO	HC	NO_x
Wood	2.5	0.75	1-30	1-35	5.0-6.0
Bagasse	8.0	-	-	-	6.0
Rice husk	8.0	-	-	-	6.0

Chapter 3

Source inventory

The first step in predicting air quality of a region is to build an inventory of pollution emitting sources. This exercise comprises three steps -

1. Identify and list the sources of pollution in a region. The sources are classified in three categories - (i) point sources (large stationary source, eg. power plants), (ii) area sources (areas with small stationary sources, eg. industrial areas with small and medium industry, human settlements and intra-city transportation), and (iii) line sources (mobile sources eg. vehicular movement on highways).
2. Estimate the extent of use of different fuels in each category of sources.
3. Estimation of source strength, which is determined by using the emission factors described in Chapter 2 and the information on the end-use technology status.

The total area of the National Capital Region (NCR) is 30,242 km^2. Of this, Haryana sub-region has the largest share (44%) followed by Uttar Pradesh (36%), Rajasthan sub-region (15%) and Union Territory of Delhi (5%). For the purpose of this study NCR is divided into grids of 24 km x 24 km. Map 1 shows the NCR boundary, sub-regions and grid structure.

In this chapter, we have described the transport network in the NCR. The rural and urban settlement patterns are considered separately because of wide differences in the fuel mix in the domestic activities. The inventory of industries is limited to only those where information on fuel consumption and emissions control technology was available.

3.1 Transport network

The traffic in the NCR is considered here in two categories: (i) traffic in major corridors and on routes connecting different cities, and (ii) traffic within a city.

Traffic flow in the corridors

Nine major corridors form the backbone of the traffic movement in the region. In addition to these major corridors, three other routes link some of the urban centres. These are:

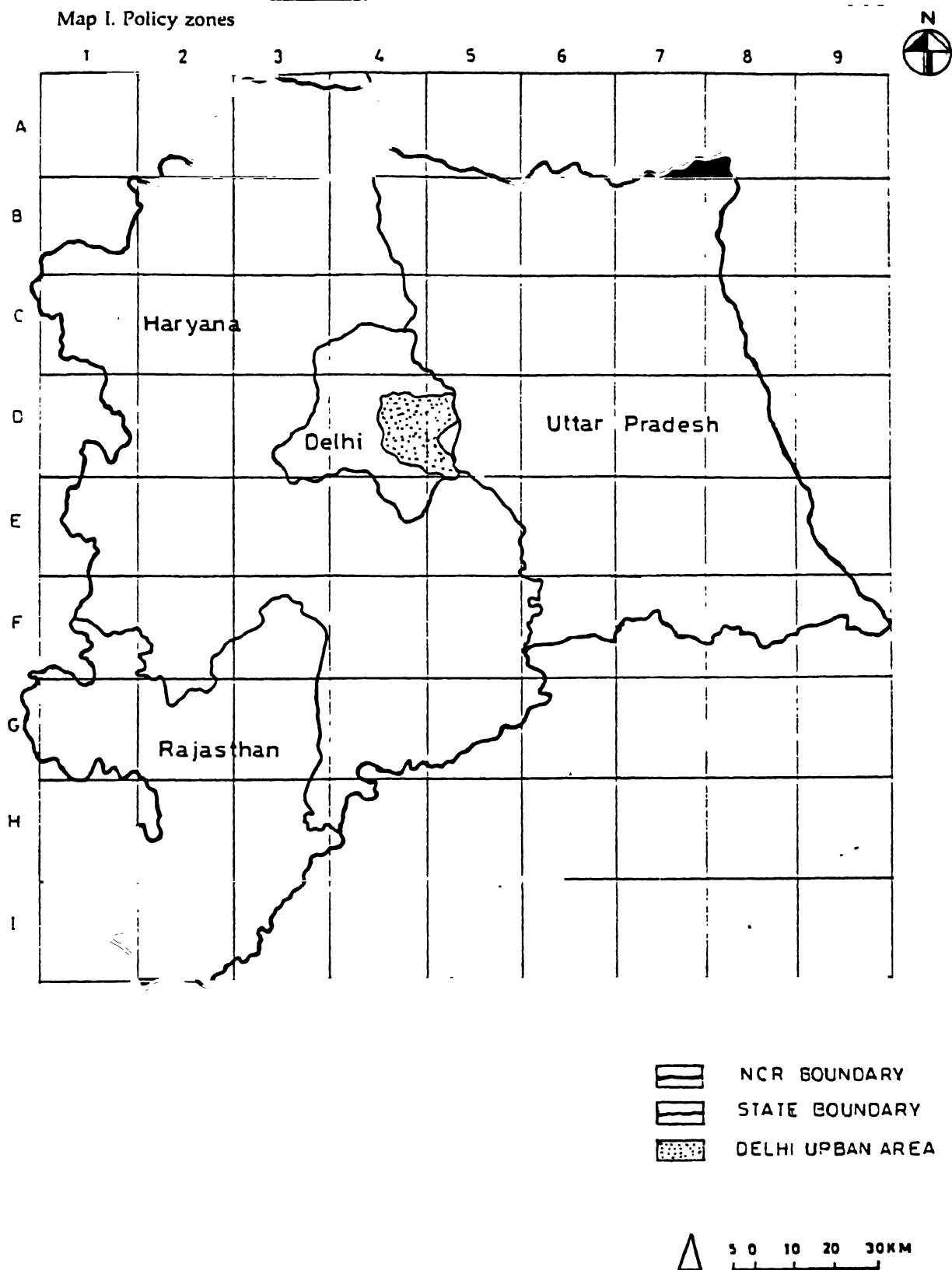
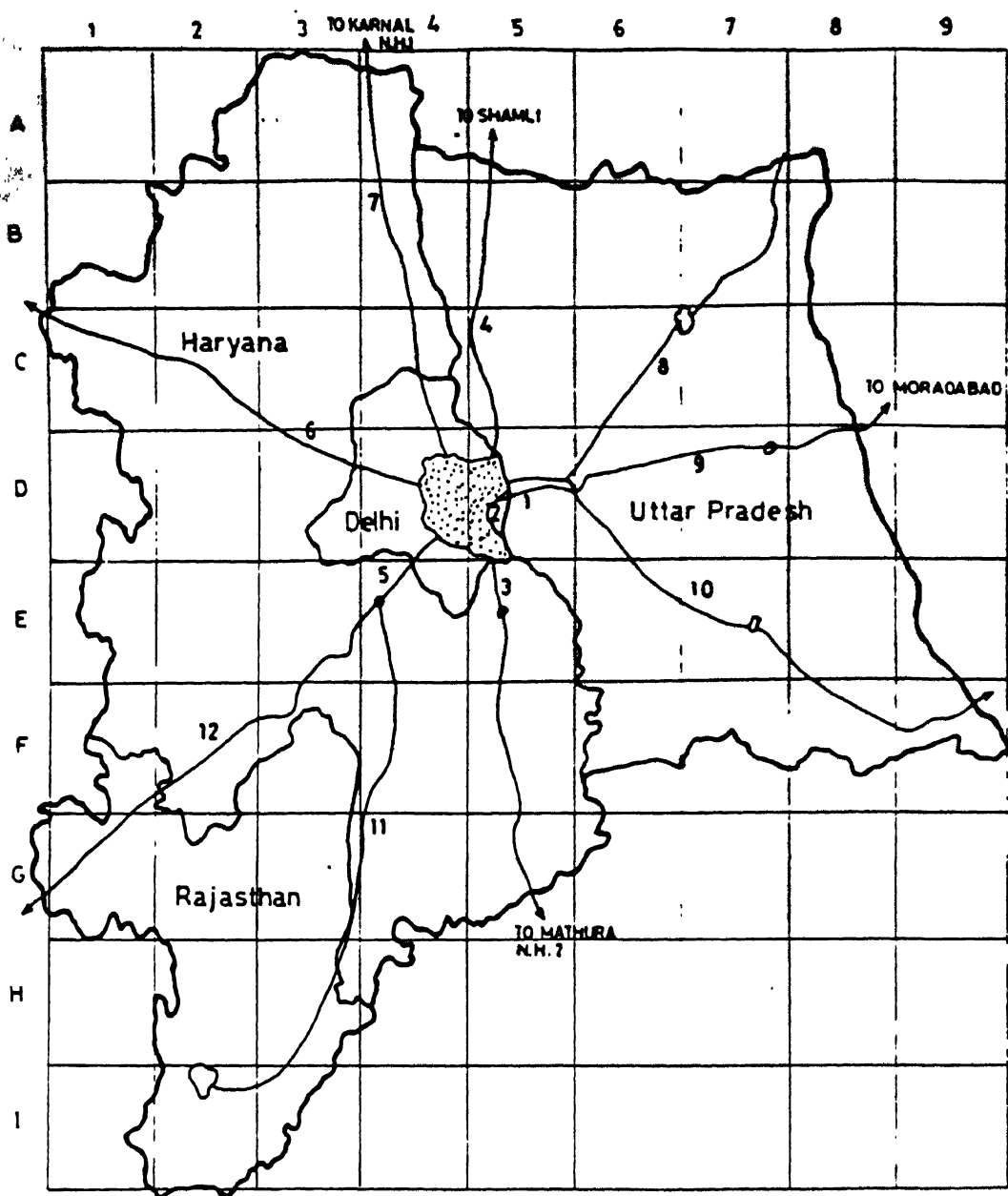
1. Delhi - Ghaziabad (NH-24)
2. Delhi - Noida
3. Delhi - Faridabad (NH-2)

4. **Delhi** - Bahadurgarh (NH-10)..
5. **Delhi** - Gurgaon (NH-8)
6. **Delhi** - Panipat (NH-1)
7. **Delhi** - Baghpat
8. Ghaziabad - Meerut
9. Ghaziabad - Hapur
10. Ghaziabad - Bulandshahr
11. Gurgaon - Sohna/Alwar
12. Gurgaon - Behror

It can be observed that five corridors (1, 3, 4, 5, 6) are national highways and the rest are state highways. Some portions of national highways are four-lane and the remaining are two-lane. Most of the state highways are single lane.

Delhi is the focal point in the region. Map 2 shows the traffic corridors in the NCR. A study carried out by Operations Research Group (ORG) and Indian Institute of Technology, Kharagpur (ORG, 1988) gives the estimated traffic intensity on different road links connecting all the important centres in the NCR for the year 1987.

Table 3.1.1 shows the traffic movement in major corridors. It gives corridor length, and number of goods vehicles, buses and passenger vehicles (cars, three-wheelers and two-wheelers) moving daily in the corridors and on major routes. About 1,31,546 vehicles move into and exit from Delhi Union Territory (DUT) every day. Out of the total vehicles plying in and out of DUT, the Delhi-Ghaziabad link carries about 42,751 vehicles i.e. 25% of the total traffic on all the 12 links put together. This is followed by Delhi-Faridabad link carrying about 30,320 vehicles (18%) and Delhi-Noida link carrying 20,310 vehicles (12%). The composition of vehicular traffic, in corridors passing through Delhi, is observed to be 67% of passenger vehicles, 8% of buses and 25% of goods vehicles. It can be inferred from the traffic density on links, that Delhi is a major point of interaction in the region.

Map I. Policy zones

Map II. Transport network

Corridor No.	Corridor		Distance (km)
	From	To	
1	Delhi	Ghaziabad	24
2	Delhi	Noida	14
3	Delhi	Faridabad	26
4	Delhi	Baghpat	45
5	Delhi	Gurgaon	22
6	Delhi	Bahadurgarh	30
7	Delhi	Panipat	38
8	Ghaziabad	Meerut	54
9	Ghaziabad	Hapur	27
10	Ghaziabad	Bulandshahr	51
11	Gurgaon	Sohna&Alwar	130
12	Gurgaon	Behror	100

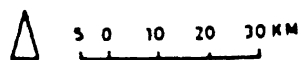



Table 3.1.1. Daily traffic movement in major corridors (1987)

Corridor No.	Vehicle movement From	To	Distance (km)	Goods vehicles	Buses (nos.)	Passenger vehicles	Total number (%)
1	Delhi	Ghaziabad	24	11432 (27) (25)	[illegible]	28714 (67) [illegible]	42751 (100) (25)
2	Delhi	Noida	14	2007 (10) (4)	[illegible] (12)	[illegible] (82)	20307 (100) (12)
3	Delhi	Faridabad	26	6795 (22) (15)	[illegible]	[illegible] (71)	30316 (100) (18)
4	Delhi	Baghpat	45	2371 (30) (5)	474 [illegible]	[illegible] (64)	7901 (100) (5)
5	Delhi	Gurgaon	22	4105 (27) (9)	[illegible]	[illegible] (63)	14995 (100) (9)
6	Delhi	Bahadurgarh	30	2513 (36) (6)	[illegible]	3706 (53)	6974 (100) (4)
7	Delhi	Panipat	98	3712 (45) (6)	[illegible]	[illegible] (41)	8302 (100) (5)
	SUBTOTAL			32935 (25) (75)	[illegible]	[illegible]	131546 (100) (77)
8	Ghaziabad	Meerut	54	3109 (28) (7)	[illegible]	[illegible]	11215 (100) (7)
9	Ghaziabad	Hapur	27	1906 (28) (4)	[illegible]	[illegible] (61)	6871 (100) (4)
10	Ghaziabad	Bulandshahr	51	2141 (24) (5)	[illegible]	[illegible]	[illegible] (100) (5)
	Gurgaon	Sohna Alwar	13	861 (19) (2)	[illegible]	[illegible]	[illegible] (3)
12	Gurgaon	Behror	106	4036 (61) (9)	[illegible]	[illegible] (30)	[illegible] (100) (4)
	TOTAL			45011 (26)	[illegible]	[illegible] (66)	[illegible]

Goods movement by road. The share of Delhi bound traffic is 75% of the aggregated traffic on all the links. Apart from Delhi, Ghaziabad (25%) is an important centre of generation and attraction in terms of goods traffic. Faridabad (15%) comes next in order of important centres. All other urban centres, irrespective of population size and economic base attract or generate limited goods traffic.

Passenger movement: The passenger movement involves transportation by the public transportation (bus) as well as movement by the passenger vehicles (two-wheelers, three-wheelers and cars).

Bus passenger movement: The DUT is the single most important centre in terms of its significance of interaction. The share of Delhi bound traffic is about 75% of the total traffic. Apart from Delhi, Ghaziabad followed by Faridabad are the important centres of generation and attraction of bus passengers. The other important centres are Noida and Gurgaon.

Vehicle passenger movement: Passenger vehicles include movement by cars/jeeps, two-wheelers and three-wheelers, etc. The overall vehicle passenger analysis reveals that, traffic generated from and attracted to the Delhi region is 79%. Ghaziabad (26%) followed by Faridabad (19%) and Noida (15%) are other important traffic generation centres.

Intra-city vehicular movement

In addition to the traffic on major link roads, intra-city traffic is a significant contributor to air pollution. However, detailed data on this component are available for Delhi urban area only. Data on traffic within other important towns such as Bulandshahr, Ghaziabad, Hapur, Meerut, Faridabad, Gurgaon, Panipat, Rohtak, Sonipat, and Alwar were not available and are not included in this data inventory.

Delhi: The growth and composition of vehicles in Delhi for the period 1970 to 1987 is shown in Table 3.1.2. There has been a drastic change in vehicle composition in Delhi in the last two decades. The two-wheelers have become the most popular mode of personal transport and their number is rising. Vehicle ownership per thousand population shows that while the number of two-wheelers has increased by more than three and a half times during this time, cars and jeeps have gone up by twice as much.

The growth rate of motor vehicles was around 10% per annum between the period 1970-71 to 1990-91. Of all the vehicles, two-wheelers have registered a maximum growth of 13% per annum. Personalized vehicles like two-wheelers and cars have registered a growth rate of 13% and 7%, as compared to public transport buses with 7%. Intermediate Public Transport (IPT) vehicle such as auto rickshaws has registered a growth rate of 8%

Table 3.1.2. Growth and composition of vehicles in Delhi (1970-91) ('000)

Vehicle type	Year						Annual growth
	70/71	81/82	84/85	85/86	86/87	90/91*	rate (%)
All fast moving vehicles	244	[illegible]	750	841	1112	1630	10
Car, jeep, van, taxi	90	[illegible]	152	165	221	350	7
Scooter, motor cycle	113	[illegible]	509	579	770	1132	12
Auto rickshaws	12	[illegible]	28	30	34.6	54	8
Buses including chartered buses	5	[illegible]	12	14	14.8	17.7	7.0
Goods vehicle	19	[illegible]	48	52	71	76	7
Others	5	[illegible]	NA	NA	NA	NA	-

Source: GOI, 1987
* ACMA, 1990

With this trend of vehicle growth, congestion on roads has increased. Because of this increasing traffic congestion, traffic speeds have reduced, resulting in the fall in energy efficiency and increased pollution. In addition, the transport is further constrained by large number of bicycles and other slow moving vehicles.

Grid-wise distribution of transport network

Table 3.1.3 shows the grid-wise distribution of transport network and its estimated lengths. This information was used in the estimation of annual emissions. Grids D5, D4, C4 and D6 have a large number of corridors, resulting in large vehicular movement and high emission levels.

Table 3.1.3. Grid-wise distribution of transport network (km)

Grid	1		2		3		4		5		6		7		8		9	
	N	D	N	D	N	D	N	D	N	D	N	D	N	D	N	D	N	D
A					7	17.5												
B							7 4	27.5 6.25	4	25	8	27.5						
C	6	32.5	6	30	6	3.75	7 4	28.75 13.75	4	13.75	8	32.5	9	5				
D					6	23.75	6 7 12	16.75 7.5 11.25	10 9 4 3 1 2 8	1.0 7.5 9.3 7.5 25 35 13.75	9 10	24.5 15.0	9	26.25				
E					12	26.25	12 11	15 21	3	27.5	10	16.25	10	32.5	10	8.75		
F			12	31.25	12	11.25	11	31.25	3	28.25					10	16.75	10	17.5
G	12	25			11	20	11	10	3	19.5								
H			11	13.75	11	31.25												
I																		

N - Number, D - Distance

3.2 Demographic and settlement pattern

Population distribution in the NCR

The National Capital Region accommodated a total population of 19.2 million in 1981 Of this, Uttar Pradesh sub-region accounted for a major share (36.3%) followed by Delhi U.T (32.4%), Haryana (25.7%) Rajasthan (5.54%) (Table 3.2.1). However, Delhi has been adding to the population unabatedly and is fast emerging as a major population absorbent among the NCR constituents, having increased its contribution from 25.1% in 1961 to 32.4% in 1981 to the population of the NCR

Table 3.2.1. Area and population

Sub-region	Area km²	Population (million)			Growth Rate %
	1981	1961	1971	1981	1971-81
Delhi UT	1483 (5)	2.7 (25)	4.1 (29)	6.2 (32)	53
Haryana	13412 (44)	2.9 (27)	3.8 (27)	4.9 (26)	30
Rajasthan	4493 (15)	0.6 (6)	0.8 (5)	1.1 (6)	39
Uttar Pradesh	10853 (36)	4.5 (42)	5.4 (39)	7.0 (36)	28
NCR	30241 (100)	10.6 (100)	14.1 (100)	19.2 (100)	36

Source: GOI, 1987
Note: Figures in brackets indicate proportions (%) to NCR total.

Urban population About 9.1 million or 47% of the population in the region resided in urban areas in 1981 as against only 39% in 1971. The fact that the NCR is getting fast urbanized is evident from the declining rural population proportion from 65% in 1961 to 61% in 1971 and 53% in 1981.

Density The density of population in the NCR was 634 per km² against the all India average of 221 in 1981. Of the constituents of the region, Delhi is the most congested with 4292 persons over km² area followed but distantly by the Uttar Pradesh subregion with 642 The other two sub-regions are significantly below the regional average (Table 3.2.2).

Table 3.2.2. Density pattern in the sub-regions

Area	Density (persons/km²)
Union Territory of Delhi	4192
Haryana	368
Rajasthan	238
Uttar Pradesh	642
NCR	634
India	221

Settlement system

Rural: There are 6677 villages (1981) in the NCR. Villages are predominantly medium sized with 55% of them having population ranging from 500-1999 persons and 21% of them 2000-4999 persons.

Urban: There are 94 urban centres in the NCR with 6 in the Union Territory of Delhi, 58 in Uttar Pradesh, 27 in Haryana and 3 in Rajasthan sub-region. There are 11 Class I urban centres including Delhi accommodating about 70% of the urban population of the NCR. As high as 64% of the entire urban population of the NCR is concentrated in Delhi alone. Of the remaining, 22% is in Uttar Pradesh followed by 13% in Haryana and 2% in Rajasthan sub-region. Class-wise proportions of urban population in Class I to IV urban centres are 10%, 1%, 5%, 3%, 2% and 0.1% respectively. Map 3 shows the towns in the NCR.

Major urban structures: The first order priority settlements (for accelerating growth) in the participating states are:

1. Uttar Pradesh sub-region: Meerut, Hapur and Bulandshahr
2. Haryana sub-region: Panipat, Rohtak, Rewari, Dharuhera and Palwal.
3. Rajasthan sub-region: Alwar and Bhiwadi.

Map III. Urban settlement pattern

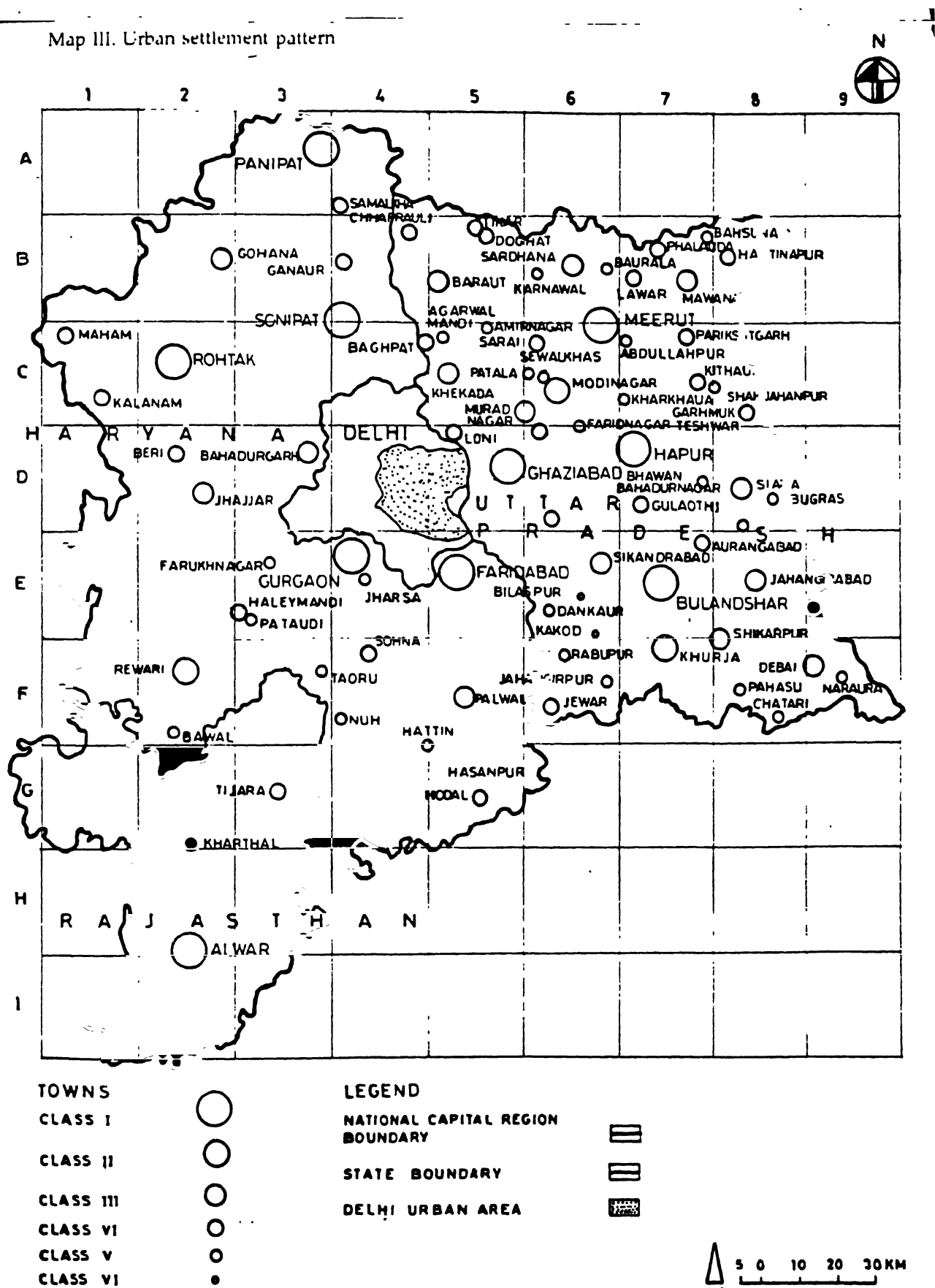



Table 3.2.3. Population of priority town (1981)

Priority town	Population (million)
Meerut	0.54
Hapur	0.1
Bulandshahr	0.1
Khurja	0.07
Palwal	0.05
Panipat	0.14
Rohtak	0.17
Rewari, Dharuhera, Bhiwadi	0.05
Alwar	0.15
Total	1.4

Source: GOI, 1987

Grid-wise population

The domestic fuel consumption is considered as a source of air pollution. Population distribution is a prerequisite to estimate the emissions from domestic sector. Because of the low intensity of source, low emission height, the stoves used for domestic cooking in an area are considered as a ground level area source. In each grid, rural and urban households are treated as separate area sources as the fuel mix is very different in rural and urban areas.

Rural population: Table 3.2.4 shows the density pattern by region. It was assumed that the distribution of rural population (density) is constant throughout the sub-region. Rural density pattern for the year 1991, in each of the four regions was estimated by dividing the projected rural population in 1991 by the area for each sub-region and was used to estimate the rural population in each grid.

Table 3.2.4. Rural density pattern

Sub-region	Population (million)	Area (km²)	Persons per km²
Delhi UT	0.442	1483	298
Uttar Pradesh	5.462	10853	503
Haryana	4.210	13412	314
Rajasthan	0.931	4493	207
NCR	11.046	30241	365

Source: GOI, 1987

Grid-wise rural population is assessed by the product of density of the sub-region in which the grid is located and the area of the grid. If the grid overlaps across two sub-regions, then the proportionate area of each region is considered for estimating the population. Table 3.2.5 shows the grid-wise rural population. There are 11 grids of U.P. sub-region with a rural population of about 12200.

Table 3.2.5. Rural population (1991)

Grid	1	2	3	4	5	6	7	8	9
A		2379	7136	3806	763	763	1526	763	
B	2379	7136	7612	9909	12205	12205	12205	2288	
C	6185	7612	7600	8018	12205	12205	12205	4577	
D	5233	7612	7491	7226	10960	12205	12205	9154	
E	4758	7612	7588	7564	7564	12205	12205	12205	3051
F	3159	2888	5833	7612	7612	7628	6103	7628	5340
G	4711	5348	5509	7136	4758	476			
H		4397	4397	952					
I		628	5025	1570					

Urban population: The population of urban areas classified into six classes (I to VI) was available for the year 1981. The population data for 1991 for Class I cities were taken from the 1991 census (GOI, 1991). The population in 1991 for other towns was projected on the basis of the average growth rate of population of the sub-region) for

during 1971-81. Table 3.2.6 shows the decadal growth rate of urban populati four sub-regions.

Table 3.2.6. Decadal growth rate of population (1971-81)

Region	Growth rate (%)
Delhi UT	58
Haryana	78
Uttar Pradesh	79
Rajasthan	57
NCR	65

Source: GOI, 1987

Table 3.2.7 shows the grid-wise urban population. The grid population are D4 (part of Delhi), D5 (part of Delhi, Ghaziabad, Loni Modinagar and others), E5 (Faridabad), A3 (Panipat) and C2 (Rohtak)

Table 3.2.7. Different categories of urban population estimated for 19[illegible]

Grid	1	2	3	4	5	6	7	8
A			216330					
B		49020	30865	112493	39934	93458	126231	[illegible]
C	45115	216000	204723	32115	140503	1063098	47019	[illegible]
D		70657	47000	7027500	2862500	205393	73055	
E		40004		150746	613000	112368	152755	[illegible]
F		75526	12938	47193	61000	57505	89000	[illegible]
G		29879	22835					
H		211000						
I								

3.3 Industries and power plants

For the air pollution modelling exercise, information is required for inc sources in order to provide input for computer analysis. The main iter total emissions, required are (a) co-ordinates of emitting point i.e. l point, (b) stack height and diameter, and (c) stack exit gas temperature

The inventory of polluting industries is compiled in this study, partly by collecting information from different pollution control boards and partly through a questionnaire survey. The questionnaire survey is the most widely used and expeditious method of collecting information on point sources to build an inventory of emissions The use of questionnaires can lead to problems in the data. These problems may be grouped into two categories: questionnaire design, and survey administration

Proper questionnaire design includes selection of appropriate questions, establishment of a suitable format, correct wording and authorship of an appropriate cover letter. The basic rule is to design the questionnaire and the letter for the person who will be asked to complete it. The questionnaire should be short, simple and as functional as possible.

The Central Pollution Control Board (CPCB) conducted an industrial survey in Okhla Industrial Area in 1983 and collected the emission data for this area. The CPCB also conducted a questionnaire survey in 1987 in order to collect the emission data from various industrial areas of Delhi. The questionnaire used by CPCB is shown in Table 3.3.1.

TERI personnel, in collaboration with the CPCB visited different State Pollution Control Board offices to collect data for emission inventory. The data collected from these sources are type of fuel, amount of fuel consumed per month, stack height and diameter type of boilers involved in the process and control devices if any. Data inventory for Haryana, and UP sub-regions are collected through this method. These industrial data were updated up to 1989. Industrial data from Alwar (Rajasthan sub-region) could not be obtained. However, total number of industries and their type is known for this area. The total fuel consumption in these industries is estimated using the data from other areas. Table 3.3.2 shows the type of industries covered for preparing the inventory of air polluting industries.

Table 3.3.1. Industrial inventory data sheet (air)

1. Industry Code
2. Industry Name
3. Industry Location
   District
   State
4. Location Description
5. Type of Industry
6. Category of Industry
7. Category Code
8. Products and its Quantity per annum
9. Raw Materials Used and its Quality
10. Manufacturing Process
11. Fuels Consumption
12. Status of Installation of Control Devices
13. Remarks

Table 3.3.2. Type of industries covered for inventory work

a. Thermal Power Plant
b. Asbestos and Ceramics Product Industry
c. Cement Plant
d. Acid Manufacturing Plant
e. Stone Crusher
f. Iron and Steel Industry
g. Pulp and Paper Industry
h. Fertilizer
i. Textile
h. Foundry
k. Rubber Products
l. Chemicals
m. Food Products

Industries in the NCR

Table 3.3.3 presents the distribution of factories in the NCR for the year 1983. The Union Territory of Delhi with 5% of NCR's land area has more factories than in Haryana sub-region with 45% share, whereas Rajasthan has the least number of factories with 14% share of land. Industries covered are: food, textiles, pulp and paper, rubber and chemicals, metal and engineering, non-metallic minerals and electrical machinery.

Table 3.3.3. Distribution of factories

	Delhi	Haryana	Rajasthan	U.P.	Total NCR
Area (km²)	147487 (4.9)	1336000 (44.6)	418945 (14.0)	1090288 (36.4)	2992720
Registered factories (1983)	4163	2666	[illegible]	1351	
Number of Workers	166000	159608	[illegible]	-	

Source: GOI, 1986

Union Territory of Delhi: Table 3.3.4 shows the different types of registered factories till 1985 in Delhi. Of these, the air polluting industries are: Textile (16%), Paper and Printing (7%), Rubber and Chemicals (13%), Metal and Engineering Products(24%), Non-metallic Mineral Products (3%) and Food Products (3%). Delhi has several industrial areas where polluting industrial units are primarily located. The Central Pollution Control Board (CPCB) carried out an inventory survey in Okhla Industrial Area (phase I, II, III), Jhilmil Tahirpur Area, Friends Colony, Loni Road-Moti Katra-GT Road in December, 1983. For Delhi, out of 4652 industries (all of them may not be air polluting) only for 114, the energy consumption pattern has been established.

Table 3.3.4. Registered factories in Delhi: group-wise - 1985

S No	Description	Number of factories						
		1979	[illegible]	1981	1982	1983	1984	1985
1	Food Products	114	[illegible]	130	142	148	153	160
2	Textile and Textile Products	457	[illegible]	545	622	666	709	746
3	Wood Products	46	[illegible]	52	56	60	66	67
4	Paper Products and Printing	230	[illegible]	255	279	290	302	315
5	Leather, Rubber and Chemicals	396	[illegible]	434	495	534	578	581
6	Non-metallic Mineral Products	55	[illegible]	51	107	114	119	146
7	Metal & Engineering Products	763	[illegible]	856	970	1032	1097	1128
8.	Manufacturing of Electrical Machinery	308	[illegible]	374	451	480	530	545
9	Manufacture and other miscellaneous transport	393	[illegible]	467	555	592	629	653
10	Generation and Transport of Electricity, Water Supply and Gas	21	22	18	21	21	21	21
11	Miscellaneous	201	225	200	219	226	241	290
	Total	2984	[illegible]	3402	3917	4163	4445	4652

Source: GOI, 1986

In Okhla Industrial Area, 54 air polluting units were identified on the basis of types of industries. Out of these, fuel consumption for 47 units is reported. There are three phases in Okhla Industrial Area. In Phase I, fuel consumption per industrial unit is more than that of Phase II and Phase III. The average fuel consumption per unit in this area is 2.4 tonnes per month, which is the minimum for all the industrial areas of UT of Delhi. Coal and fuel oil are the main fuels used in this sub-region. The major polluting industries in this sub-region are chemical (24%), foundry (47%), and textile (10%).

Total number of air polluting industrial units in Shahadra Industrial Area is found to be 67; 26 in Jhilmil Tahirpur Industrial Area, 30 in Friends Colony Industrial Area and 11 in Loni Road-Moti Katra-G.T. Road Industrial Area. Average fuel consumption per month per industry for Shahadra area is 41.34 tonnes. The break-up for Jhilmil Tahirpur, Friends Colony and Loni Road-Moti Katra-G.T. Road Industrial Areas is 21.74, 33.0 and 108.0 tonnes per month per industrial unit respectively.

There are six other air polluting industrial areas in the UT of Delhi, namely Najafgarh Road, Lawrence Road, Wazirpur, Kirti Nagar, DLF and Moti Nagar. Stone crushers are the major source of air pollution (particulates) in this sub-region.

Uttar Pradesh: Ghaziabad, Meerut and Bulandshahr are the three districts that come under NCR. Table 3.3.5 shows the number of registered factories in UP sub-region. The study of types of industries in various towns reveals an interesting pattern. Out of 1351 registered factories in the UP sub-region in 1985, Ghaziabad district alone had 60%, Meerut district accounted for 30% and 10% in Bulandshahr. Ghaziabad is the only city in the sub-region where all types of industries are located. Modinagar is dominated by cotton textile and rubber industries. The contribution of the food products and metal and alloy industries is significant in this industrial town. Meerut represents a large number of industries though predominant industries are food products and cotton textile. Hapur has a concentration of food product industries, Khurja of non-metallic mineral products namely ceramics and potteries. Sikandrabad has chemicals and chemical products industries. Bulandshahr has a diversified industrial base, though industries such as food products and cotton textiles have gained prominence. Other towns have diversified industrial base but the contribution of these industries is insignificant. In Rohtak district, the leading industries are wood and wood products, non-metallic mineral products, chemical and basic metal and alloys. Bahadurgarh industrial area is famous for sanitary ware, tubes, glass products, and small metal products and some leather and rubber products. Mohindergarh district specializes in the manufacture of non-metallic mineral products, followed by wood products and basic metals and alloys.

Table 3.3.5. District-wise concentration of registered factories in UP sub-region

District	No. of registered factories
Meerut	401
Bulandshahr	138
Ghaziabad	812

Source: GOI, 1986

Ghaziabad: Coal is used by the largest number of industries followed by fuel oil in this district. All kinds of fuels are used here, i.e. coal, rice husk, furnace oil, low distillate oil, wood, bagasse, LPG and diesel oil. Diesel oil is mainly used for gensets. Out of 812 air polluting industries, data has been obtained from only 109.

Meerut: The main industries in this sub-region are sugar, paper, alcohol and cloth-printing. Water pollution is of greater concern than air pollution. The main fuels here are coal, bagasse and rice husk. Out of 401, data were collected from 32 industries.

Bulandshahr: Sugar, paper and machineries are the main industries in this sub-region. Consequently, water-pollution is the main problem associated with these industries. Out of 138, energy consumption pattern for only 24 industries has been obtained. However, air pollution is also of great concern. In this sub-region bagasse is also the main fuel (74.7%), followed by rice husk (11.5%) Instead of furnace oil, low distillate oils used by the largest number of industries

Haryana: Area-wise, Haryana is the largest (44%) and most industrialized sub-region in the NCR. Table 3.3.6 gives the district-wise number of registered factories in this sub-region. Within the sub-region, there has been an overwhelming concentration of industries in Faridabad, Karnal and Sonipat districts, though Faridabad ranked first in the list. Industries manufacturing non-metallic mineral products, wood and wood products, machinery and machine tools, basic metal and alloys, and food products are the leading industries in the sub-region. Faridabad-Ballabhgarh industrial complex is concentrated with transport and earth moving machinery, cotton textiles, powerloom products, hosiery, paper, machine embroidery, agricultural implements, electrical appliances and basic metals and alloys. Gurgaon district has succeeded in attracting a wide range of industries, with those producing non-metallic minerals, transport equipment and parts, metal products and parts, wood and wood products as leading ones. Karnal district has units manufacturing food products, non metallic mineral products, coal, silk and synthetic fibres, wood and wood products, machinery and machinery tools. In Faridabad district, about 7000 industries (registered and unregistered) exist including small units. Out of these, 330 units are air polluting.

From energy consumption pattern in this area, it is seen that coal is the main fuel (38.8%) followed by furnace oil (31.0%).

Table 3.3.6. Registered factories in Haryana sub-region - 1983

District	No.of registered factories
Gurgaon	210
Faridabad	1197
Mohindergarh	106
Karnal	650
Sonipat	275
Rohtak	228
Total	2666

Source: GOI, 1986

Coal is the most popular fuel used in Sonipat, Panipat, Rohtak and Gurgaon districts. The amount of fuel oil used in industrial boilers is also significant for the above mentioned regions. Fuel oil acts as a substitute fuel for coal. Rice husk and bagasse are consumed in large quantities, but the user industries are few in number. Wood is used by large number of industries but in small quantities.

Rajasthan: Rajasthan sub-region comprises six tehsils of Alwar district. Table 3.3.7 shows the distribution of factories in this sub-region. Out of these six tehsils, Alwar and Behror tehsils have 36 air polluting industrial units - most of them are chemical manufacturing and agro-based industries. Both water and air pollution are of major concern in this sub-region.

Table 3.3.7. Distribution of registered factories (industries-wise in Alwar district 1983)

Type of Industry	Units
1. Food products	15
2. Manufacturing of textiles	10
3. Sawing and planning of wood	24
4. Printing, publishing & allied activities	44
5. Manufacturing of paints, varnishes & lacquers	2
6. Manufacturing of drugs and medicines	20
7. Manufacturing of glass and glass products	1
8. Manufacturing of structural stone goods, stone dressing and steel industries	16
9. Iron and steel industries	38
10. Manufacturing of electrical machinery, apparatus and appliances	4
11. Cement	3
12. Others	60
Total	237

Source : GOI, 1986

No fuel consumption pattern of this region is available for calculating the emission inventory. Hence, on the basis of number of industries and their types, the annual emissions from these industries are calculated in accordance with the fuel consumption pattern of other industrial areas.

The grid-wise distribution of industries included in the inventory is carried out and fuel consumption in them is estimated. This analysis is also carried out according to different industrial centres also and is presented in the next section.

Power plants

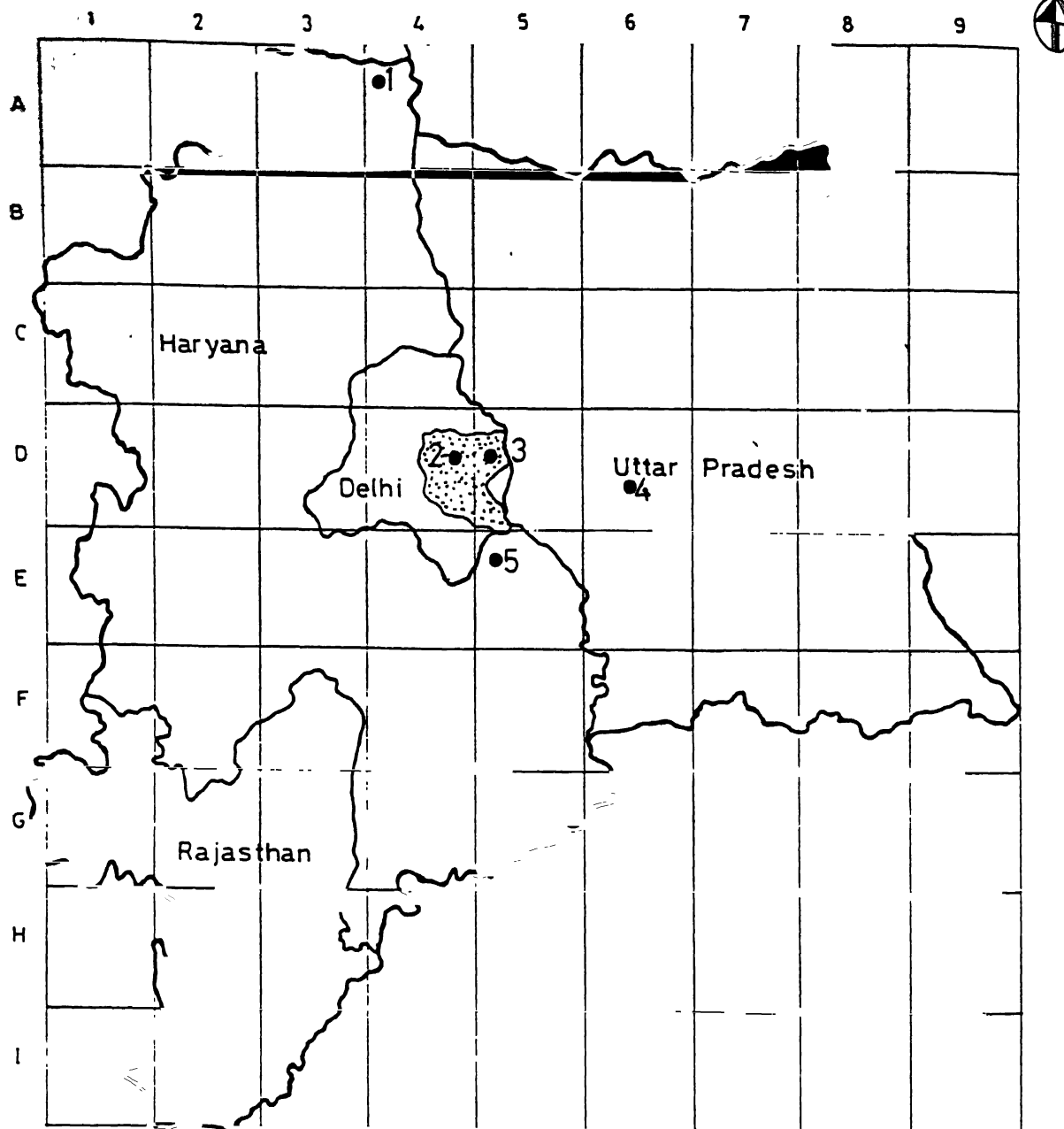
There are six thermal and one gas-based power plants in NCR. Out of the six thermal power plants, three are in the Delhi UT These are at Rajghat, IP Estate and Badarpur. Panipat, Faridabad and Dadri has a thermal station each. The gas-based power plant in the UT of Delhi operates only to meet the peak demand. As a result its contribution to air pollution is negligible Hence in the present study its contribution is not accounted for.

Coal is the main fuel used in these thermal stations Fuel oil is also used, though in very small quantity (during start-up operation). Table 3.3.8 shows the capacity,

grid-wise location and amount of coal consumed by these thermal stations. Map 4 shows location of power plants in the region.

Table 3.3.8. Fuel consumption in power plants

Location of the plant	Grid	Capacity (MW)	Coal consumption (t/month)
Delhi (Rajghat & IP Estate)	D4	299.1	108943
Badarpur	D5	720	262249
Dadri	D6	210	76489
Faridabad	E5	195	71026
Panipat	A4	440	160264

Map IV. Location of power plants

Number	Location of power plant
1	Panipat
2.	Delhi (I.P. & Rajghat)
3	Badarpur
4	Dadri
5	Faridabad

Chapter 4

Annual emissions

4.1 Transportation

Transportation sector is an major source of pollution in the National Capital Region. The estimation of annual emissions in a region requires data on (i) emission factors for different pollutants for each vehicle category, (ii) number of each type of vehicle, and (iii) utilization pattern.

The data on emission factors as described in the section 2.1 is available for the Indian vehicles but does not take into account the influence of speed of operation, age of vehicles and road conditions. These factors influence the emission factors to a considerable extent. Thus, it is necessary to update this information so as to present the realistic scenario.

The database composition of vehicles and their utilization is described in 3.1 However, the existing data base does not include the mix of passenger vehicles on the corridors. The data on vehicle utilization of vehicles in the city of Delhi were not available and hence the national statistics compiled from different sources were used. In order to get a realistic picture of the pollution status in Delhi, it is necessary to carry out a survey that considers the city specific parameters, which in turn depend on the size of the city, the living standards, and mobility pattern of commuters.

In this study, transport in the 12 major corridors in the NCR and the intra-city vehicular movement in the city of Delhi is considered for estimating annual pollution loading in each grid of the NCR.

Method of estimation

Emissions in corridors: The annual emissions were computed by the product of vehicles plying in the corridor per day, length of the corridor and the emission factor for each type of pollutant.

$$AEjk = \sum_{i} Ni * Lk * Eij * 365$$

where,

AEjk - Annual emission in corridor k and pollutant j (tonnes)

Ni - Number of vehicles of type i passing the road per day

Lk - Length of the corridor (kilometres)

Eij - Emission factor of vehicle type i and pollutant j (g/km)

i - vehicle type

j - pollutant type

k - corridor

Emission rate in corridor: Emissions of pollutant j per unit length of the corridor k is estimated as

$$ERjk\ (g/m\text{-}hr) = \sum_{i} Ni * EFij/24 * 1000$$

where,

ERjk - Emission rate of pollutant j on corridor k

Emissions resulting from intra-city movement: The variables used for estimating emissions due to intra-city vehicular movement are : number of vehicles by type, average distance travelled in an year (vehicle utilization) and emission factor for different pollutant from each type of vehicle.

The total annual emissions were computed as

$$AEj = \sum_{i} Ni * Uti * EFij$$

where,

AEj - Annual emissions of pollutant j

Ni - Number of vehicles of type i

Uti - Annual utilization of vehicle type i (kilometres)

Eij - Emission Factor for pollutant j from vehicle i (g/km)

i - Vehicle type

n - Number of vehicle types

j - Pollutant type (TSP, SO_2, CO, NO_x, HC, Pb)

The fleet strength was computed from the time series data on registration published by the Automative Components Manufacturers Association of India (ACMA, 1989). Table 4.1.1 shows the average distance travelled in km (annual vehicle utilization) for each category of vehicles.

Table 4.1.1. Annual vehicle utilization

Vehicle type	Vehicle utilization (km/yr)
Two-wheelers	9000
Three-wheelers	25000
Cars, taxis, jeeps	9500
Buses	70000
Light commercial vehicles	20000

Source: GOI, 1989

Pollution emissions in corridors

Table 4.1.2 shows the emissions of different pollutants in 12 major corridors of the region. Figure 4.1.1 shows the contribution of different modes to the total emission, aggregated over all the links. Over 26300 tonnes of CO, 7500 tonnes of HC, 8000 tonnes of NO_x, 1250 tonnes of SO_2, 10 tonnes of Pb and 230 tonnes of TSP are emitted annually. CO, HC and NO_x have high emission levels. CO and HC are mainly contributed by the passenger modes of transport (over 86%), whereas, a major share of NO_x (59%), SO_2 (66%) and TSP (69%) is emitted from diesel driven buses and trucks. Pb is exclusively emitted from the petrol operated passenger vehicles.

Table 4.1.3 shows emission rate (g/m-h) for each pollutant in each of the corridor. In Table 4.1.4 we have ranked the corridors in the order of decreasing emission rates of a pollutant. Delhi-Ghaziabad (Corridor 1) corridor has the maximum emission rate for each of the pollutant, followed by Delhi-Faridabad (Corridor 3). Delhi-Noida (Corridor 2) link is ranked third for the pollutants CO, HC and Pb because of the high passenger vehicular density. Other corridors with higher emissions are Delhi-Gurgaon (Corridor 5) and Ghaziabad-Meerut (Corridor 8).

Figures 4.1.2 to 4.1.6 show the modal contribution to each pollutant type in the major corridors of the region. Passenger vehicles contribute over 80% of CO and HC in all the corridors. Diesel vehicles contribute over 75% of NO_x and over 90% of SO_2. TSP is equally shared by passenger vehicles and by diesel operated vehicles.

Table 4.1.2. Annual emissions in corridors (1987)

Corridor No.	Vehicle movement		Pollutant (tonnes per year)					
	From	To	CO	HC	NO_x	SO_2	Pb	TSP
1.	Delhi	Ghaziabad	4553	1288	1118	169	2	31
2.	Delhi	Noida	1462	406	227	31	1	5
3.	Delhi	Faridabad	3646	1026	794	117	1	21
4.	Delhi	Baghpat	1525	434	411	63	1	11
5.	Delhi	Gurgaon	1407	402	411	64	1	12
6.	Delhi	Bahadurgarh	802	234	307	49	0	9
7.	Delhi	Panipat	2677	808	1459	241	1	45
8.	Ghaziabad	Meerut	2587	740	755	117	1	21
9.	Ghaziabad	Hapur	777	223	244	38	0	7
10.	Ghaziabad	Bulandshahr	2063	584	513	78	1	14
11.	Gurgaon	Sohna/Alwar	3036	844	500	69	1	12
12.	Gurgaon	Behror	1842	574	1287	217	1	41
Total			26377	7563	8026	1252	10	230

Fig. 4.1.1. Annual emission inventory in corridors by vehicle type

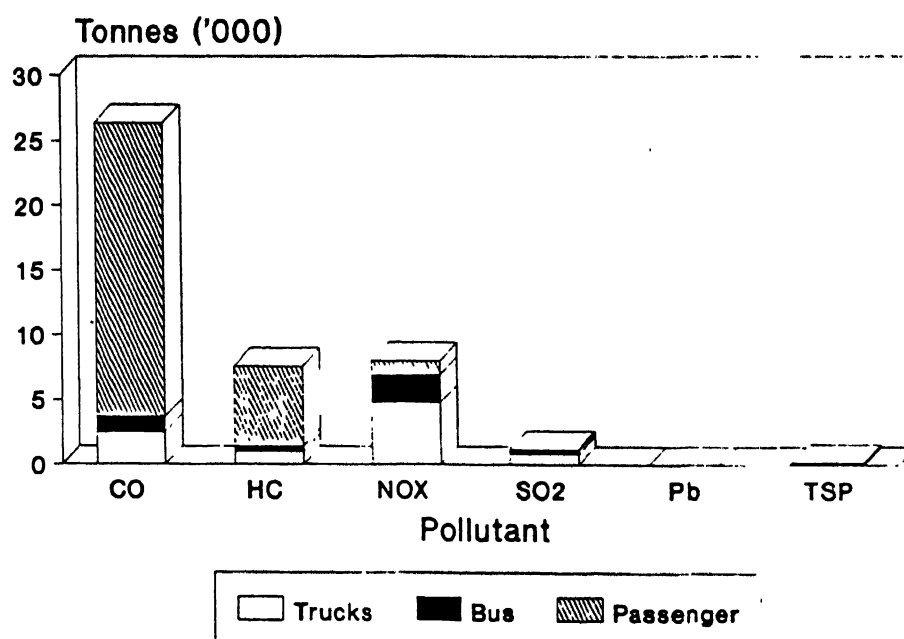



Fig 4.1.2 Contribution to pollution load by vehicle type (corridor no 1)

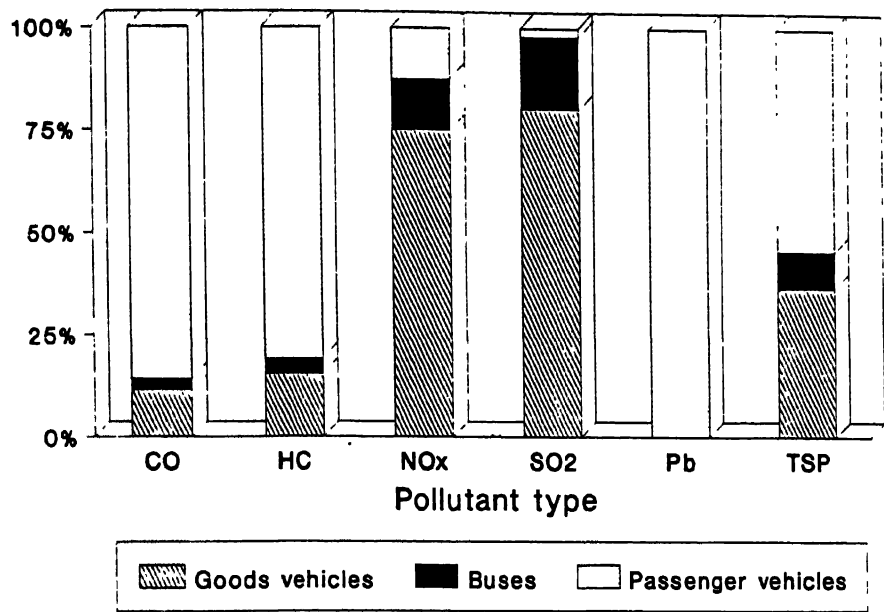



Fig 4.1.3 Contribution to pollution load by vehicle type (corridor no 3)

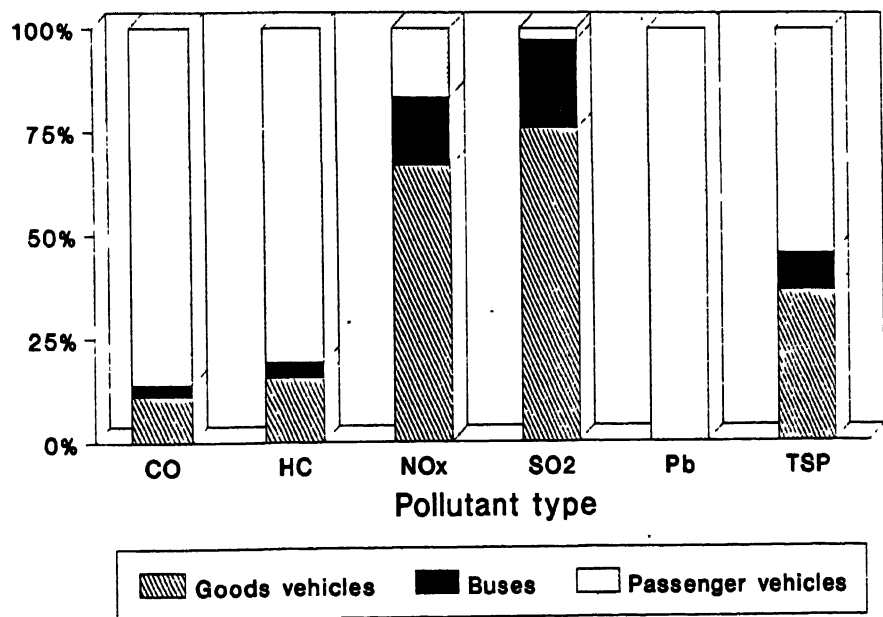



Fig 4.1.4 Contribution to pollution load by vehicle type (corridor no 2)

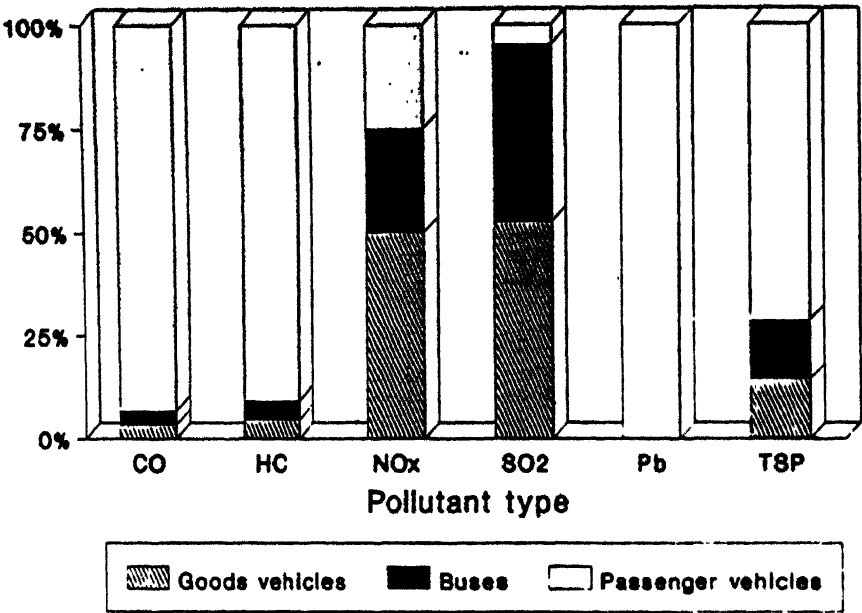



Fig 4.1.5 Contribution to pollution load by vehicle type (corridor no 7)

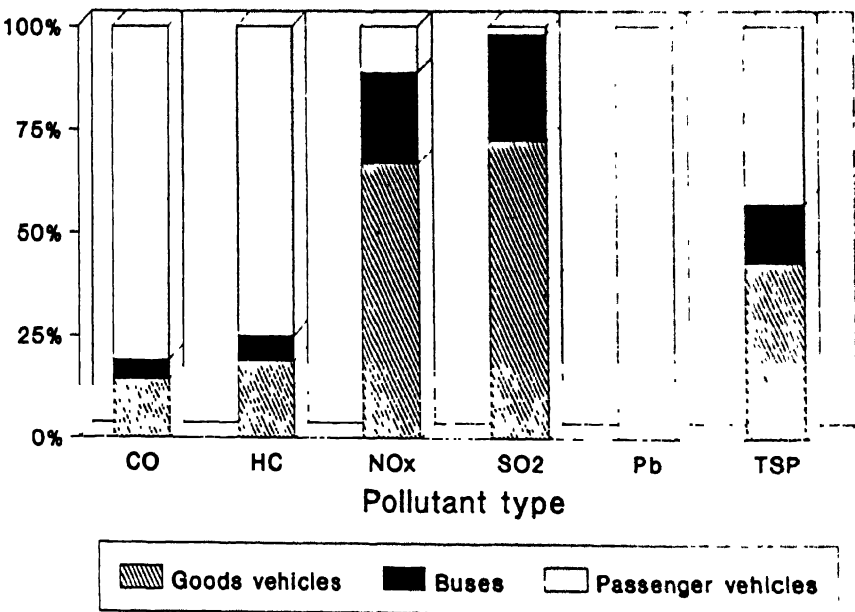
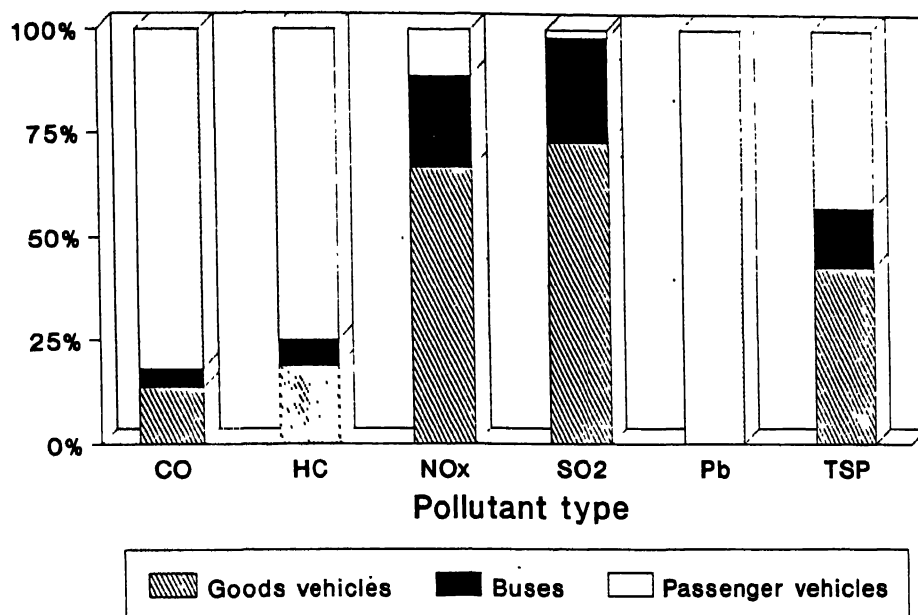



Table 4.1.3. Emission rates for 1987 due to transportation on major corridors

Corridor No.	Pollutant ($g\ m^{-1}\ h^{-1}$)					
	CO	HC	NO_x	SO_2	Pb	TSP
1	21.65	6.13	5.32	0.80	0.0086	0.15
2	11.92	3.31	1.85	0.25	0.0050	0.04
3	16.01	4.50	3.49	0.51	0.0065	0.09
4	3.87	1.10	1.04	0.16	0.0015	0.03
5	7.30	2.09	2.13	0.33	0.0028	0.06
6	3.05	0.89	1.17	0.19	0.0011	0.03
7	3.12	0.94	1.70	0.28	0.0010	0.05
8	5.47	1.56	1.60	0.25	0.0021	0.05
9	3.29	0.94	1.03	0.16	0.0013	0.03
10	4.62	1.31	1.15	0.17	0.0018	0.03
11	2.67	0.74	0.44	0.06	0.0011	0.01
12	2.10	0.66	1.47	0.25	0.0006	0.05

Table 4.1.4. Emissions on links: ranking

Corridor No.	Pollutant					
	CO	HC	NO_x	SO_2	Pb	TSP
1	1	1	1	1	1	1
2	3	3	3	3	3	3
3	2	2	5	5	2	5
4	5	5	2	7	5	7
5	8	8	7	2	8	12
6	10	10	8	8	10	8
7	4	4	12	12	4	2
8	9	9	6	6	9	6
9	7	7	10	10	6	10
10	6	6	4	9	11	9
11	11	11	9	4	7	4
12	12	12	11	11	12	11

Emission inventory in Delhi

Table 4.1.5 shows the mode-wise emissions of different pollutants due to intra-city vehicular movement in Delhi. In terms of total tonnage, CO, HC and NO_x are the major pollutants. Over 186000 tonnes of CO, 77230 tonnes of HC and 17400 tonnes of NO_x are emitted annually. Table 4.1.6 shows the share of different vehicles in the pollution loading. It can be observed that petrol driven vehicles are the major contributors of CO (97%) and HC (97%), whereas SO_2 (86%) and NO_x (71%) are mainly contributed by diesel driven vehicles. Pb is exclusively emitted from petrol driven vehicles and TSP from diesel vehicles.

Two-wheelers and cars are the major sources of pollution of CO and HC, whereas, bus is the major polluting source of NO_x, SO_2 and TSP.

Table 4.1.5. Mode-wise emissions of different pollutants

Vehicle type	Emission inventory (tonnes/year)				
	CO	HC	NO_x	SO_2	Pb
Petrol driven					
Two-wheelers	84582.8	52787.8	0.0	132.5	64.2
Three-wheelers	16411.9	10249.1	0.0	38.9	15.5
Cars/Taxis(P)	78522.2	11665.6	5130.2	173.2	37.9
Sub Total	179516.9	74702.5	5130.2	344.5	117.6
Diesel driven					
Buses	5572.7	2162.4	10527.7	1828.7	0.0
Light Commercial Vehicles	886.7	342.6	1679.5	292.2	0.0
Jeeps(D)	78.0	30.1	147.7	25.7	0.0
Sub Total	6537.5	2535.1	12354.8	2146.7	0.0
Total	186054.4	77237.6	17485.0	2491.2	117.6

Table 4.1.6. Modal share in pollution loading (percentage)

Vehicle type	CO	HC	NO_x	SO_2	Pb	TSP
Petrol driven						
Two-wheelers	45.5	68.3	0.0	5.3	54.6	0.0
Three-wheelers	8.8	13.3	0.0	1.6	13.2	0.0
Cars/Taxis (P)	42.2	15.1	29.3	7.0	32.2	0.0
Sub Total	96.5	96.7	29.3	13.8	100.0	0.0
Diesel driven						
Buses	3.0	2.8	60.2	73.4	0.0	85.1
Light Commercial Vehicles	0.5	0.4	9.6	11.7	0.0	13.7
Jeeps (D)	0.0	0.0	0.8	1.0	0.0	1.2
Sub Total	3.5	3.3	70.7	86.2	0.0	100.0
Total	100.0	100.0	100.0	100.0	100.0	100.0

Grid-wise annual emissions

Grid-wise annual emissions are estimated by the product of grid-wise distribution of transport network and the emission rate per unit length of the corridor. Table 3.1.3 given in chapter 3 gives the distribution of type of corridor and its estimated length in each of the grids. Table 4.1.3 gives the emission rates for 1987 due to transportation in major corridors. Emissions due to intra-city transportation movement (in Delhi) is allocated to two grids (D4, D5) based on the proportion of the urban area of Delhi.

Tables 4.1.7 to 4.1.12 shows the grid-wise annual emissions due to vehicular movement. It can be observed from the tables that grids D4, D5, F5, E5 and G5 have high emission levels in decreasing order of significance for all the pollutants. This is because of high emission rate in corridors passing through these grids and also due to high intra-city vehicular emissions in Delhi (which falls in the grids D4 and D5).

Table 4.1.7. Annual emissions of CO from transport sector (tonnes/year)

Grid	1	2	3	4	5	6	7	8	9
A			478	137					
B				963	847	1317			
C	868	802	100	1251	466	1557	360		
D			635	780 + 125264*	8370 + 60790*	1312	755		
E			484	773	3857	657	1315	354	
F		576	207	730	3962			657	708
G	461		467	234	2735				
H		321	730						
I									

* Emissions due to intra-city vehicular movement in Delhi

Table 4.1.8. Annual emissions of HC from transport sector (tonnes/year)

Grid	1	2	3	4	5	6	7	8	9
A			144	41					
B				287	241	377			
C	253	234	29	370	133	445	103		
D			185	234 + 52002*	2368 + 2536*	374	217		
E			151	224	1085	186	372	100	
F		179	65	203	1114			186	200
G	143		130	65	769				
H		89	203						
I									

Emissions due to intra-city vehicular movement in Delhi

Table 4.1.9. Annual emissions of NO_x from transport sector (tonnes/year)

Grid	1	2	3	4	5	6	7	8	9
A			260	74					
B				466	228	385			
C	332	307	38	553	126	455	113		
D			243	397 + 11772*	2037 + 5713*	372	237		
E			338	275	840	164	327	88	
F		402	145	120	863			164	176
G	322		77	38	769				
H		53	120						
I									

* Emissions due to intra-city vehicular movement in Delhi

Table 4.1.10. Annual emissions of SO_2 from transport sector (tonnes/year)

Grid	1	2	3	4	5	6	7	8	9
A			43	12					
B				76	35	60			
C	53	49	6	90	19	70	18		
D			39	65 + 1677*	307 + 814*	57	37		
E			57	44	124	25	49	13	
F		68	24	17	127			25	27
G	54		11	5	88				
H		7	17						
I									

* Emissions due to intra-city vehicular movement in Delhi

Table 4.1.11. Annual emissions of Pb from transport sector (tonnes/year)

Grid	1	2	3	4	5	6	7	8	9
A			0.16						
B						1			
C						1			
D				79*	3 + 38*	1			
E					2		1		
F					2				
G					1				
H									
I									

* Emissions due to intra-city vehicular movement in Delhi

Table 4.1.12. Annual emissions of TSP from transport sector (tonnes/year)

Grid	1	2	3	4	5	6	7	8	9
A			8	2					
B				14	6	11			
C	10	9	1	17	4*	13	3		
D			7	12 + 274*	56 + 133*	11	7		
E			11	8	22	4	9	2	
F		13	5	3	23			4	5
G	10		2	1	16				
H		1	3						
I									

Emissions due to intra-city vehicular movement in Delhi

4.2 Estimation of grid-wise annual emissions from the domestic sector

Grid-wise emissions are estimated by the product of the population (urban and rural) with the per capita fuel consumption of different fuels and the emission factor for each type of pollutant. Per capita fuel consumption for rural and urban areas is compiled from secondary sources (NCAER 1985, TERI, 1991), for each of the sub-regions. Per capita fuel consumption in urban Delhi is compiled from a recent study carried out in the city of Delhi (TERI 1989). Table 4.2.1 and 4.2.2 show the per capita fuel consumption of each fuel type for rural and urban areas respectively. The per capita emissions for different classes of urban areas is in kgcr (as given in Table 4.2.2) which was converted into kg (Table 4.2.3) using the conversion factors. Tables 4.2.4 and 4.2.5 show the annual emission in each grid from rural domestic consumption. TSP and CO have high levels of emissions. It is observed that cells B, C, D, E (5, 6, 7) have high emission levels. This is because these cells are a part of the UP sub-region for which the rural population density and fuel consumption are high. Tables 4.2.6 to 4.2.9 show the emission resulting from urban domestic fuel consumption. The grids with the highest levels of emissions are D4 (Delhi), D5 (Parts of Delhi, Ghaziabad and Loni), C6 (Meerut), E5 (Faridabad), C2 (Rohtak), H2 (Alwar) and A3 (Panipat).

Table 4.2.1. Per capita fuel consumption in rural areas (kg/year)

Fuel consumption	Firewood	Twigs	Dung-cake	Agricultural wastes
Haryana	11	39	256	79
Uttar Pradesh	21	119	211	63
Rajasthan	49	159	141	15
Delhi	41	52	132	61

Source: NCAER, 1985

Table 4.2.2. Per capita annual fuel consumption in different class of urban areas (kgcr)

Class of urban area	Kerosene	LPG	Coke	Firewood	Other biofuels
I	19.8	7.2	21.3	29.6	12.9
II	18.7	6.4	22.5	31.8	12.6
III	9.5	2.9	18.8	38.6	23.9
IV, V, VI	16.6	1.5	14.3	32.9	28.2

Source: NCAER, 1985

Table 4.2.3. Per capita annual fuel consumption in different class of urban areas (kg)

Class of urban area	Kerosene	LPG	Coke	Firewood	Other biofuels
I	10.82	0.70	3.05	31.16	43.00
II	1.42	9.11	7.37	1.02	0.29
III	5.50	0.32	2.55	37.82	81.56
IV	2.48	4.71	5.61	0.87	0.35
V	2.48	4.71	5.61	0.87	0.35
VI	2.48	4.71	5.61	0.87	0.35
Delhi*	15.58	19.82	0	0	0

Source: *TERI, 1989

Table 4.2.4. Annual emissions of TSP from domestic fuel consumption in rural areas (tonnes)

Grid	1	2	3	4	5	6	7	8	9
A		3.81	11.44	6.10	1.17	1.17	2.34	1.17	
B	3.81	11.44	12.20	15.88	18.74	18.74	18.74	3.51	
C	9.91	12.20	12.18	8.32	18.74	18.74	18.74	7.03	
D	8.39	12.20	7.87	7.50	16.83	18.74	18.74	14.05	
E	7.63	12.20	12.16	12.12	12.12	18.74	18.74	18.74	4.68
F	5.06	37.41	7.00	12.20	12.20	11.71	9.37	11.71	8.20
G	5.65	6.42	6.61	11.44	7.68	0.76			
H	0.00	5.28	5.28	1.14					
I	0.00	0.75	6.03	1.88					

Table 4.2.5. Annual emissions of CO from domestic fuel consumption in rural areas (tonnes)

Grid	1	2	3	4	5	6	7	8	9
A		26.33	78.99	42.13	8.43	8.43	[illegible]	8.43	
B	26.33	78 99	84.26	109.68	134.77	134.77	134.77	25 26	
C	68.46	84.26	84.12	60.93	134.77	134.77	134.77	50 54	
D	57.92	84.26	57 68	54.91	121.02	134.77	134.77	101 08	
E	52.67	84.26	83.99	83.73	83 73	134.77	134.77	134.77	33.69
F	34 97	258.33	52 12	84 26	84 26	84 23	67 39	84 23	58 96
G	42.10	47.79	49 23	78 99	52.67	5.27			
H	0.00	39 29	39 29	8.51					
I	0.00	5.61	44.90	14.03					

Table 4.2.6. Annual emissions of TSP from domestic fuel consumption in urban areas (tonnes)

Grid	1	2	3	4	5	6	7	8	9
A	0.00	0.00	72.10	0.00	0.00	0.00	0.00	0.00	0.00
B	0.00	26.37	3.78	49.78	4.89	34.88	44.71	2.67	0.00
C	5.52	78.03	73.95	3.93	56.89	334.40	5.76	2.03	0.00
D	0.00	27.51	25.28	2538.61	1034.05	60 25	26.37	0.00	0.00
E	0.00	5.71	0.00	50.70	221.44	47.30	49.99	54.58	0.00
F	0.00	11.22	1.58	5.78	32.81	7.04	13.78	25.99	2.19
G	0.00	3 66	2.80	0.00	4.30	0.00	0.00	0.00	0.00
H	0.00	76.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00
I	0	0	0	0	0	0	0	0	0

Table 4.2.7. Annual emissions of CO from domestic fuel consumption in urban areas (tonnes)

Grid	1	2	3	4	5	6	7	8	9
A	0.00	0.00	461.82	0.00	0.00	0.00	0.00	0.00	0.00
B	0.00	169.63	8.24	306.75	10.66	205.10	258.57	5.81	0.00
C	12.04	514.63	487.76	8.57	342.51	2046.31	12.55	4.43	0.00
D	0.00	163.80	162.64	16743.21	6819.99	365.81	153.46	0.00	0.00
E	0.00	12.45	0.00	325.84	1460.49	287.84	317.92	336.32	0.00
F	0.00	20.25	3.45	12.59	211.09	15.35	23.89	152.72	4.78
G	0 00	7.97	6.09	0.00	9.36	0.00	0.00	0.00	0.00
H	0 00	502.71	0 00	0.00	0.00	0.00	0.00	0.00	0.00
I	0	0	0	0	0	0	0	0	0

Table 4.2.8. Annual emissions of SO_2 from domestic fuel consumption in urban areas (tonnes)

Grid	1	2	3	4	5	6	7	8	9
A	0.00	0.00	[illegible]	0.00	0.00	0.00	0.00	0.00	0.00
B	0.00	1.66	2.30	4.87	2.98	4.66	6.58	1.62	0.00
C	3.37	8.77	8.31	2.40	6.60	56.82	3.51	1.34	0.00
D	0.00	3.42	1.59	[illegible]	[illegible]	10.32	3.74	0.00	0.00
E	0.00	3.48	0.00	6.65	[illegible]	5.10	6.94	5.34	0.00
F	0.00	7.07	0.97	3.52	2.07	4.29	8.73	3.50	1.34
G	0.00	2.23	1.70	0.00	2.62	0.00	0.00	0.00	0.00
H	0.00	8.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00
I	0	0	0	0	0	0	0	0	0

Table 4.2.9. Annual emissions of NO_x from domestic fuel consumption in urban areas (tonnes)

Grid	1	2	3	4	5	6	7	8	9
A	0.00	0.00	4.22	0.00	0.00	0.00	0.00	0.00	0.00
B	0.00	0.58	1.45	2.24	1.88	2.41	3.46	1.03	0.00
C	2.13	3.43	3.25	1.51	3.25	29.00	2.22	0.78	0.00
D	0.00	1.73	0.56	111.48	45.41	5.08	1.96	0.00	0.00
E	0.00	2.20	0.00	2.88	9.72	2.45	3.10	2.47	0.00
F	0.00	5.40	0.61	2.22	0.72	2.71	6.88	1.81	0.84
G	0.00	1.41	1.08	0.00	1.65	0.00	0.00	0.00	0.00
H	0.00	3.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00
I	0	0	0	0	0	0	0	0	0

4.3 Industries and power plants

The total emissions of different pollutants from industries in an area have been calculated using types of fuels and their total consumption (per month), boiler type and control equipment efficiency data. Emission factor data given in Table 3.1.3 is used in estimating total monthly emissions in a region. Tables 4.3.1 and 4.3.2 show the district-wise and grid-wise total emissions of pollutants in NCR.

In Okhla Industrial Area (Grid D5) carbon monoxide ranks the highest in contribution to total emissions. It contributes 21.4 tonnes/month (t/m) (58%)

followed by HC (4.82 t/m), TSP (4.78 t/m) and SO_2 (4.22 t/m). The reason for large CO emission is because of inefficient burning of fuels such as coal and furnace oil.

Taking all the industrial areas of Shahdara (Grid D5) together, CO emerges as the single largest pollutant followed by SO_2. The contribution of SO_2 is 24.9 tonnes per month (16%), CO is 79.9 tonnes per month (52%) and 19.20 tonnes per month is particulate matter (13%). Hydrocarbons and oxides of nitrogen are 12.4% and 63% respectively. The inefficient burning of fuels in industries is responsible for generating such large amounts of CO as pollutants.

There are six other air polluting industrial areas existing in the UT of Delhi, namely Nazafgarh Road, Lawrence Road, Wazirpur, Kirti Nagar, DLF and Moti Nagar. High levels of TSP concentration prevail in Nazafgarh Road and Lawrence Road Industrial Areas. This particulate matter is released primarily form stone crushers and brick kilns. No fuel consumption pattern is available for these six industrial areas. However, the amount of TSP and SO_2 has been reported. Lawrence Road and Nazafgarh Industrial Area contribute 1402 and 794.5 t/m respectively. The amount of SO_2 is of serious concern in the Kirti Nagar Industrial Area.

For Ghaziabad, CO emerges as the single largest pollutant followed by particulate matter. This can be attributed to the use of coal in the different industries in this region. Though bagasse is burnt in few industries, its contribution to particulate matter is the highest than any other fuel. In Bulandshahr, rice husk is the main fuel and consequently particulate matter is the single largest pollutant followed by CO in this region. For Meerut, CO is the main pollutant owing to the consumption of coal as the commonly used fuel. Diesel oil and rice husk are also used in large quantities, thus contributing to particulate matter.

The amount of different pollutants emitted from Faridabad industrial areas are also of great concern. Total amount of particulate matter emitted is approximately 225.7 t/m and 420 t/m of CO. The contribution of other pollutants in this area is not insignificant. The amount of SO_2, unburnt hydrocarbons and NO_x are 114, 129 and 96 t/m respectively. The amount of unburnt hydrocarbons is primarily because of furnace oil used in these industries.

For Panipat, Rohtak, Sonipat and Gurgaon regions, CO is the main pollutant. The contribution of CO is primarily from the use of coal as fuel. The contribution of SO_2 is significant in Panipat, Sonipat and Rohtak districts. The use of coal and furnace oil is the main reason for SO_2 emissions.

The fuel consumption pattern for Alwar district has been computed on the basis of the number of industries that exist in this region. The main fuels used in this region are coal and rice husk, and as a result the emissions of CO and particulate matter are significant. Their contributions are 40.3 and 11.5 t/m respectively. The emission of HC is also significant and contributes 11.8 t/m which is mainly released from coal and wood burning.

Table 4.3.1. Energy pattern and pollution load (districtwise)

Area	Fuel Type	Fuel Consumption t/m	Emission of Pollutants (t/m)				
			TSP	SO_2	CO	HC	NO_x
Delhi							
Okhla Industrial Area							
Phase I	Coal	215.6	2.156	1.638	9.702	2.156	0.323
	Furnace Oil	51.0	0.045	0.344	0.378	0.007	0.328
	LDO	10.0	0.003	0.041	0.007	0.001	0.037
	Wood	6.2	0.031	0.005	0.094	0.113	0.375
	Total		2.235	2.030	9.841	2.277	0.716
Phase II	Coal	245.5	2.455	1.866	11.048	2.455	0.368
	Furnace Oil	12.0	0.011	0.082	0.009	0.002	0.090
	LDO	20.9	0.006	0.085	0.016	0.003	0.057
	Wood	2.5	0.013	0.002	0.038	0.045	0.015
	Total		2.484	2.034	11.109	2.505	0.530
Phase III	Coal	4.0	0.004	0.030	0.180	0.040	0.006
	Furnace Oil	18.0	0.016	0.122	0.013	0.003	0.135
	Total		0.056	0.153	0.193	0.043	0.141
Shahdara Industrial Area							
Jhilmil	Coal	422.1	4.221	3.200	18.995	4.221	0.633
Tahirpur	Furnace Oil	974.0	0.865	6.618	0.722	0.138	0.731
Industrial	Wood	4.0	0.020	0.003	0.060	0.072	0.024
	Total		5.106	9.821	19.776	4.431	1.388
Friends Colony							
	Coal	732.0	7.320	5.563	32.940	7.320	1.098
	Furnace Oil	134.5	0.119	0.914	0.100	0.01	1.009
	Wood	89.5	0.447	0.067	1.342	1.611	0.537
	Total		7.887	6.544	34.382	8.950	2.644
Loni Road,							
Moti Ram,	Coal	561.0	5.610	4.264	25.245	5.610	0.841
G.T. Road	Furnace Oil	626.5	0.557	4.256	0.464	0.088	4.700
	Total		6.166	8.520	25.709	5.698	5.540
Nazafgarh Road			794.500	75.300			
Lawrence Road			1402.000	20.400			
Wazirpur			254.100	182.000			
Kirti Nagar			66.100	300.000			
DLF			55.70	2.100			
Moti Nagar			33.400	1.100			
Uttar Pradesh							
Meerut							
	Coal	8132.79	81.33	61.81	365.97	81.3	12.2
	Furnace Oil	11.52	0.01	0.06	0.01	0.01	0.08
	LDO'	0.01					
	Diesel Oil	7202.32	1.62	33.56	4.08	0.84	17.5
	Wood	187.18	0.47	0.14	2.9	3.37	1.03
	Rice Husk	4168.5	33.35				2.63
	Bagasse	4092	32.74				2.58
	Total	23794.32	149.52	95.57	372.96	85.55	36.02
Ghaziabad							
	Coal	23872.82	238.73	181.43	1074.28	238.73	35.81
	Furnace Oil	4852.11	3.3	25.22	2.75	0.57	32.75
	LDO	19673.69	4.43	91.68	11.15	2.3	47.81
	Diesel Oil	1380.05	0.31	6.43	0.78	0.16	3.35
	Wood	1773.67	4.43	1.33	27.49	31.93	9.75
	Rice Husk	7331.67	58.65				4.39
	Bagasse	74749.4	597.99				44.85
	Total	133633.41	907.84	306.09	1116.45	273.69	178.71
Bulandshahr							
	Coal	2824	28.24	21.46	127.08	28.24	4.24
	Furnace Oil	63.3	0.04	0.33	0.03	0.01	0.42
	LDO	1707.9	0.38	7.96	0.97	0.2	4.15
	Diesel Oil	624.3	0.22	0.06	1.37	1.59	0.48
	Wood	88.53	92.91				6.97
	Rice Husk	11614.15	225				16.87
	Bagasse	28125					
	Total	45047.18	346.79	29.81	129.45	30.04	33.13

Haryana							
Panipat							
	Coal	42069	420.6	319.8	1893	420.6	63
	Furnace Oil	14564.4	11.1	84	9	1.8	130.8
	LDO	1275	0.87	6.63	0.72	0.14	10.3
	HSD	915	0.2	4.26	0.52	0.1	6.2
	Wood	879.64	2.2	0.66	13.63	15.83	4.84
	Rice Husk	305.7	2.44				0.18
	Bagasse	421.91	3.37				0.25
	Total	60430.65	440.78	415.35	1916.87	438.47	215.57
Sonipat							
	Coal	31364.43	313.64	238.37	1411.39	313.64	47.05
	Furnace Oil	36137.7	24.57	187.82	20.49	4.23	243.92
	LDO	1176.3	0.26	5.48	0.67	0.14	2.86
	Diesel Oil	852	0.19	3.97	0.48	0.1	2.07
	Wood	4240.5	10.6	3.18	65.73	7633	23.32
	Rice Husk	363.3	2.91				0.22
	Bagasse	15.2	0.12				0.01
	Natural Gas	2700.5	0.43	0.02	0.73	0.12	7.56
	Total	76849.93	352.72	438.84	1499.49	394.56	327.01
Rohtak							
	Coal	11942.46	119.42	90.76	537.4	119.42	17.91
	Furnace Oil	8148	5.54	42.35	4.62	0.95	54.99
	LDO	1686.6	0.38	7.86	0.96	0.2	4.1
	Diesel Oil	1494.6	0.34	6.96	0.85	0.17	3.63
	Wood	2084.2	5.21	1.56	32.3	37.5	11.46
	Rice Husk	1135.8	9.08				0.68
	Bagasse	1074	8.59				0.64
	Total	27565.66	148.56	149.49	576.13	158.24	93.41
Faridabad							
	Coal	8393.5	83.93	63.79	377.71	83.93	12.59
	Furnace Oil	6719	5.97	45.65	4.98	0.95	59.28
	LDO	639.35	0.18	2.58	0.48	0.08	2.12
	Diesel Oil	27.75	0.01	0.13	0.01	.0.01	0.07
	Wood	2474	12.37	1.86	37.11	44.53	12.37
	Rice Husk	15402.1	123.21				9.24
	Total	33655.7	225.67	114.01	420.29	129.	95.67
Gurgaon							
	Coal	565.85	5.66	4.32	25.59	5.66	0.85
	Furnace Oil	470.33	0.32	2.44	0.27	0.05	3.17
	LDO	14.32	0.01	0.07	0.01	0.01	0.03
	Diesel Oil	30.43	0.01	0.14	0.02	0.01	0.07
	Wood	129.53	0.32	0.09	2	2.33	0.71
	Rice Husk	81.26	0.65				0.05
	Bagasse	121.88	0.97				0.07
	Total	1413.6	7.94	7.06	27.89	8.06	4.95
Rajasthan							
Alwar							
	Coal	819	8.19	6.22	36.85	8.19	1.23
	Furnace Oil	678	0.46	3.52	0.38	0.08	4.58
	LDO	64.72	0.01	0.3	0.04	0.01	0.16
	Wood	192.93	0.48	0.14	2.99	3.47	1.06
	Rice Husk	298	2.38				0.18
	Total	2052.65	11.52	10.18	40.26	11.75	7.21

* Has been taken into account in DO emission

LDO - Light Distillate Oil, HSD - High Speed Diesel

Table 4.3.2. Grid-wise total emission of TSP (t/year)

Grid	1	2	3	4	5	6	7	8	9
A									
				756					
B						612	276		
C	1104			4236	132	1476			
D			10188	17952	13884	132	240		
				510	1224	360			
E				108	1428	3264			96
					336				
F		120	16.8		1272		792		
G					1.2				
H		130.8							
I									

Table 4.3.3. Grid-wise total emission of SO_2 (t/year)

Grid	1	2	3	4	5	6	7	8	9
A				4980					
				14616					
B						294	25.2		
C	1116			5268	40.8	606			
D			1308	333.6	9192	64.8	24		
				9936	23916	6972			
E				96	1332	3264			31.2
					6480				
F		15.6	1.44		34.8		27.6		
G					0.96				
H		121.2							
I									

Table 4.3.4. Grid-wise total emission of CO (t/year)

Grid	1	2	3	4	5	6	7	8	9
A				23004					
				1920					
B						1740	156		
C	4284			17994	156	3232.8			
D			2572.8	252	12993.6	458.4	93.6		
				1308	3147.6	918			
E				352.8	4764	1276.8			120
					852				
F		48	50.4		314.4		162		
G					5.52				
H		432							
I									

Table 4.3.5. Grid-wise total emission of HC (t/year)

Grid	1	2	3	4	5	6	7	8	9
A				5262					
				960					
B						386.4	61.2		
C	1179.6			4735.2	38.4	734.4			
D			708	57.6	3171.6	62.4	24		
				654	1573.2	458.4			
E				109.2	1382.4	295.2			30
					426				
F		12	16.8		174		36		
G					1.2				
H		126							
I									

Table 4.3.6. Grid-wise total emission of No_x (t/year)

Grid	1	2	3	4	5	6	7	8	9
A				2640					
				14424					
B						74.4	678		
C	781.2			3924	26.4	232.8			
D			468	16.8	2191.2	499.2	26.4		
				9804	23604	6885.6			
E				74.4	1014	373.2			20.4
					6390				
F		13.2	10.8		139.2		111.6		
G					0.24				
H		92.4			0				
I					0				

* For Power Plants

Emissions from power plants

There are six power plants (thermal) in the NCR. These are: Rajghat (15 MW), I.P. Estate (284.1 MW), Badarpur (720 MW), Panipat (440 MW), Faridabad (195 MW) and Dadri (210 MW) power plants. There is one gas-based power plant in Delhi sub-region. The power plant is operated only during peak demand hours Since the total time of operation of the plant is very small, the emissions, basically NO_x from this plant have not been taken into account. Coal and fuel oil are used as fuel for these power plants. The total emissions of different pollutants have been calculated using total fuel consumption level, emission factors and efficiency of the electrostatic precipitators (ESPs). The emission factors for coal and oil have been used in accordance with the type of boiler used and the efficiency of the control devices. Electro static precipitators are used in thermal power stations to remove the particulate matter in bulk. The emissions of particulate matter from power plants have been computed using the following equation:

$E_c = (1-n_c/100)\ (EF)\ (P)$

where,

E_c - Controlled emissions, t/month

n_c - Control device efficiency, percent

EF - Emission factor, g/kg

P - Fuel consumption rate, t/month

Coal is washed before using in these power plants to reduce the ash content level. The level of ash content in coal has been assumed to be 20% and the sulphur level in coal has been assumed to be 0.4%. The efficiency of ESPs is taken to be 99.7%. The total pollutants for these power plants are shown in Table 4.3.7. Emissions of SO_2 and NO_x are significantly high. Badarpur followed by Panipat and Delhi emits large quantities of pollutants annually.

Table 4.3.7. Total pollutants emitted from power plants in NCR

Name of the power plant	Capacity (MW)	PM	SO_2	CO	HCS	NO_x
		tons per month				
Panipat	440	62.5	1218.0	160.3	80.1	1202.0
Delhi (I.P. and Rajghat)	299.1	42.5	828.0	109.0	54.5	817.0
Badarpur	720	102.3	1993	262.3	131.1	1967
Faridabad	195	27.7	540	71	35.5	532.5
Dadri	210	29.8	581	76.5	38.2	573.7

4.4 Grid-wise total annual emissions

The annual emissions in each of the grid from domestic (rural and urban), industry and transport sector are aggregated and presented in Tables 4.4.1 to 4.4.5. Emission from the intra-city transport sector and from the power plants are not included in the tables because of the incomplete database of emissions in urban transport sector other than for Delhi and due to the release of pollutants at high level because of high stack height.

The pollution loading of TSP, CO, SO_2, NO_x, and HC from all the sectors put together are in the order of 68300, 151129, 27508, 25479, and 29557 tonnes respectively. Table 4.4.6 shows the sectoral contribution of different pollutants to the total emission loading. Industrial sector accounts for a major share of all the pollutants, especially TSP and SO_2 (over 91%). This is followed by the transport sector. NO_x and HC are equally shared by industry and transport. A substantial amount of CO is also contributed by the domestic sector.

Table 4.4.1. Annual emissions of TSP (tonnes)

Grid	1	2	3	4	5	6	7	8	9
A	0	4	92	5300	1	1	2	1	0
B	4	38	16	80	30	677	343	6	0
C	1129	99	87	4268	212	1291	27	9	0
D	8	40	10228	20510	14991	222	292	14	0
E	8	18	23	179	1684	3334	78	75	101
F	5	182	30	21	1340	811	23	42	15
G	16	10	11	12	29	1	0	0	0
H	0	214	8	1	0	0	0	0	0
I	0	1	6	2	0	0	0	0	0
Total	1170	605	10502	30370	18286	6336	766	147	116

Table 4.4.2. Annual emissions of CO (tonnes)

Grid	1	2	3	4	5	6	7	8	9
A	0	26	1019	23183	8	8	17	8	0
B	26	249	92	1379	992	3036	551	31	0
C	5236	1401	672	19314	1099	6310	507	55	0
D	58	248	3428	17831	28303	2271	1137	101	0
E	53	97	568	1535	10165	2356	1768	825	154
F	35	903	313	827	4572	100	253	894	772
G	503	56	522	313	2803	5	0	0	0
H	0	1296	769	9	0	0	0	0	0
I	0	6	45	14	0	0	0	0	0
Total	5911	4281	7429	64406	47944	14086	4232	1915	925

Table 4.4.3. Annual emissions of SO_2 (tonnes)

Grid	1	2	3	4	5	6	7	8	9
A	0	0	53	4997	0	0	0	0	0
B	0	2	2	81	38	359	32	2	0
C	1171	58	14	5360	66	565	22	1	0
D	0	3	1350	684	9615	132	66	0	0
E	0	3	57	147	1482	310	56	18	31
F	0	91	39	21	129	4	9	29	28
G	54	2	13	5	125	28	0	0	0
H	0	137	17	0	1	0	0	0	0
I	0	0	0	0	0	0	0	0	0
Total	1225	296	1545	11294	11457	1398	184	50	60

Table 4.4.4. Annual emissions (NO_x) (tonnes)

Grid	1	2	3	4	5	6	7	8	9
A	0	0	264	2714	0	0	0	0	0
B	0	1	1	468	230	462	681	1	0
C	1115	310	41	4479	156	602	115	1	0
D	0	2	712	525	4274	876	265	0	0
E	0	2	338	352	1864	540	330	90	21
F	0	421	156	261	975	3	7	166	177
G	322	1	78	38	771	0	0	0	0
H	0	149	120	0	0	0	0	0	0
I	0	0	0	0	0	0	0	0	0
Total	1437	886	1711	8838	8270	2483	1399	258	198

Table 4.4.5. Annual emissions (HC) (tonnes)

Grid	1	2	3	4	5	6	7	8	9
A	0	0	144	5303	0	0	0	0	0
B	0	0	0	287	241	763	61	0	0
C	1433	234	29	5105	171	634	103	0	0
D	0	0	893	292	5540	436	241	0	0
E	0	0	151	333	2467	481	372	100	30
F	0	191	82	203	1288	0	36	186	200
G	143	0	130	65	770	0	0	0	0
H	0	215	203	0	0	0	0	0	0
I	0	0	0	0	0	0	0	0	0
Total	1576	640	1632	11588	10478	2315	813	286	230

Table 4.4.6. Sectoral emissions

Pollutant	Domestic (%)	Industry (%)	Transport (%)	Total Tons
TSP	8.4	91.1	0.5	68300
CO	24.8	48.6	26.6	151129
SO_2	2.3	91.1	6.6	27508
NO_x	1.1	52.2	46.7	25479
HC	-	61.1	38.9	29557

To identify the sensitive zones in the NCR, five sensitive grids were identified for each of the pollutant. The grids in which the levels of emission are observed to be high are given in Table 4.4.7. The important areas that are falling in these grids are given in the Table 4.4.8.

Table 4.4.7. Sensitive grids in the order of decreasing significance

Pollutant	1	2	3	4	5
TSP	D4	D5	D3	A4	C4
CO	D5	A4	C4	D4	E5
SO_2	D5	C4	A4	E5	D3
NO_x	C4	D5	A4	E5	C3
HC	D5	A4	C4	E5	C1

Table 4.4.8. Location of grids

Grid No	Area
A4	Panipat
C1	Meham, Kalanam, Rohtak
C3	Part of Sonipat
C4	Baghpat, Parts of Sonipat and Delhi
D3	Bahadurgarh, Parts of Delhi
D4	Delhi
D5	Parts of Delhi, Ghaziabad, Loni
E5	Faridabad

In order to identify the tolerance of areas in the identified grids, for further expansion of an activity, the sectoral contribution in each of the sensitive grids are assessed. Tables 4.4.9 to 4.4.16 shows the sectoral contribution of different pollutants in each of the grid. Industrial sector is the major contributor in all the grids (except a few) for all the pollutants. This is followed by the transport sector.

Grid C3 has no industrial activity and the transport sector is responsible for the NO_x emissions. Similarly, in the grid D4 (Delhi region), CO is mainly contributed by domestic fuel combustion (CO from the intra-city transport sector is very high but was not included as explained previously). In the grid D4, transport sector followed by the domestic sector is the major contributor of NO_x.

Table 4.4.9. Sectoral contribution of emission loading in grid A4

Pollutant	Domestic	Industry	Transport
TSP	0.1	99.8	
CO	0.2	99.2	0.6
SO_2	0	99.8	0.2
NO_x	0	97.3	2.7
HC	0	99.2	0.8

Table 4.4.10. Sectoral contribution of emission loading in grid C4

Pollutant	Domestic	Industry	Transport
TSP	0.3	99.3	0.4
CO	0.4	93.2	6.5
SO_2	0	98.3	1.7
NO_x	0	87.6	12.3
HC	0	92.8	7.2

Table 4.4.11. Sectoral contribution of emission loading in grid D5

Pollutant	Domestic	Industry	Transport
TSP	7	92.6	0.4
CO	24.5	45.9	29.6
SO_2	1.2	95.6	3.2
NO_x	1.1	51.3	47.7
HC	0	57.3	42.7

Table 4.4.12. Sectoral contribution of emission loading in grid E5

Pollutant	Domestic	Industry	Transport
TSP			
CO	15.2	46.9	37.9
SO_2	1.7	90	8.4
NO_x	0.5	54.4	45.1
HC	0	56	44

Table 4.4.13. Sectoral contribution of emission loading in grid C1

Pollutant	Domestic	Industry	Transport
TSP			
CO			
SO_2			
NO_x			
HC	0	82.3	17.7

Table 4.4.14. Sectoral contribution of emission loading in grid C3

Pollutant	Domestic	Industry	Transport
TSP			
CO			
SO_2			
NO_x			
HC	8	0	92

Table 4.4.15. Sectoral contribution of emission loading in grid D3

Pollutant	Domestic	Industry	Transport
TSP	0.3	99.6	0.1
CO			
SO_2			
NO_x			
HC			

Table 4.4.16. Sectoral contribution of emission loading in grid D4

Pollutant	Domestic	Industry	Transport
TSP	12.4	87.5	0.1
CO	94.2	1.4	4.4
SO_2	0.1	97	2.9
NO_x	21.2	3.2	75.6
HC			

Chapter 5

Meteorological data

This section describes briefly the micro-meteorological parameters that influence the air quality. The status of different meteorological stations in the NCR is explained and data gaps and lacunae in the meteorological parameters are identified.

5.1 Meteorological parameters

The meteorological parameters pertinent to the problem of air pollution are those governing the transport and diffusion of the pollutant in the atmosphere. These are:

- Wind speed and direction
- Atmospheric stability
- Mixing height
- Intensity and pattern of rainfall

Wind speed and direction

Wind speed and direction are the basic meteorological parameters, which affect the plume rise and transportation of pollutants discharged into the atmosphere from the sources. Theoretical considerations show that the concentrations are inversely proportional to wind speed. In the layer of the atmosphere above the ground, wind speed varies with height. Generally, it increases with height.

These two basic wind parameters i.e. speed and direction are expressed in the form of a frequency table or in a wind-rose form. Wind-rose represents 8 or 16 wind directions with each direction making an angle of 45° or 22.5° with the next. Wind speed is expressed in m/s or kmph. The wind speeds are divided into four classes (Table 5.1.1).

Table 5.1.1. Classification of wind speeds

Class	Mean wind speed	
	km/h	m/s
I	2.5	0.7
II	7.5	2.1
III	15.0	4.2
IV	25.0	6.9

Map 5 shows a typical wind-rose for the Delhi region. Wind-rose is generally expressed for a month, a season or a year based on the levels of variation of wind direction. Wind speed is measured by an anemometer and wind direction is measured by wind vane. Wind speeds less than 2 km/h are known as calms. A calm bias correction has to be applied to wind data. The frequency of calms is distributed among the lowest wind speed class for each direction as follows:

$$N_a = \frac{N_w N_c}{N_w}$$

where,

N_a - frequency of calms to be added to a particular direction

N_c - total frequency of calms

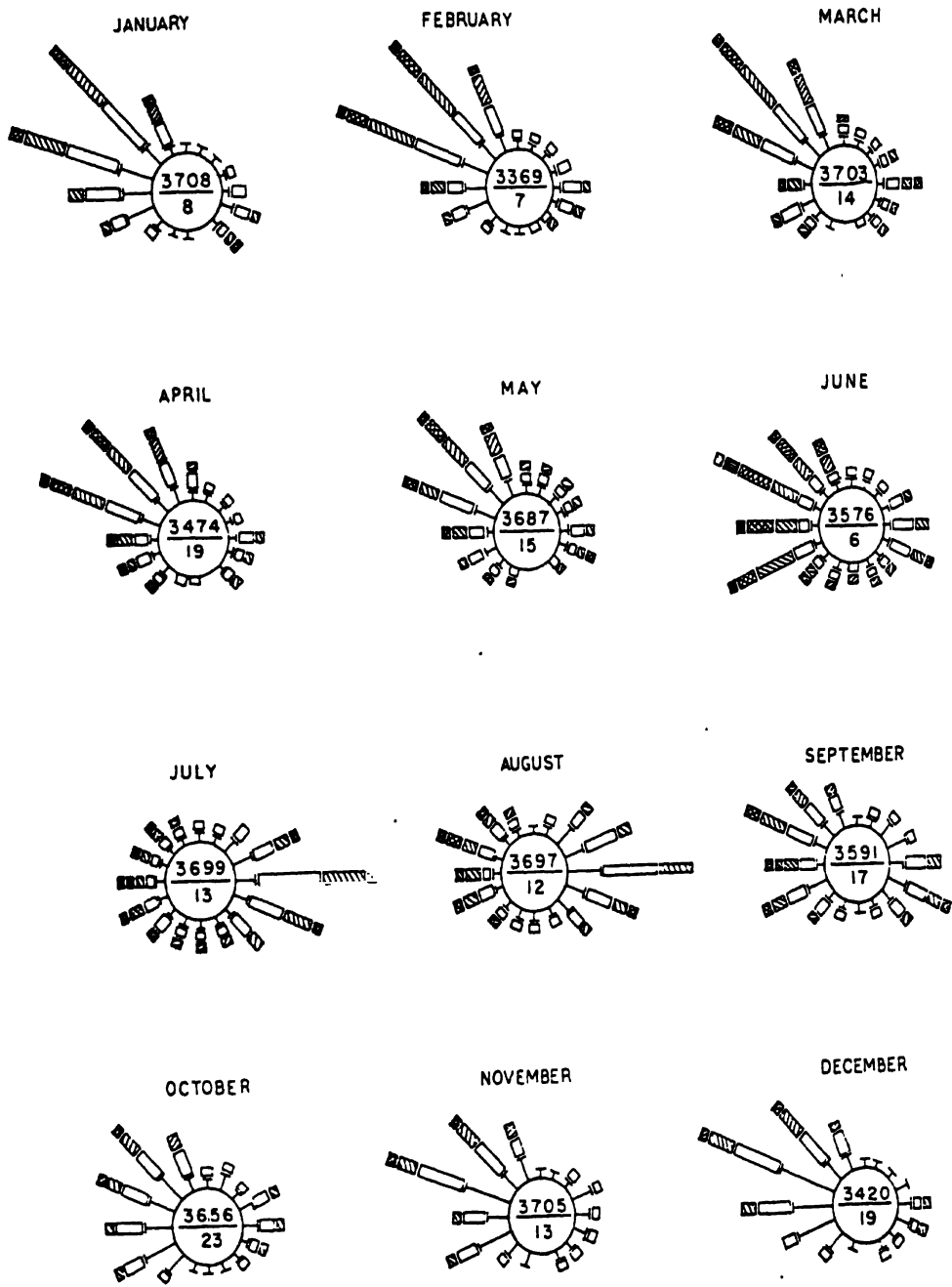
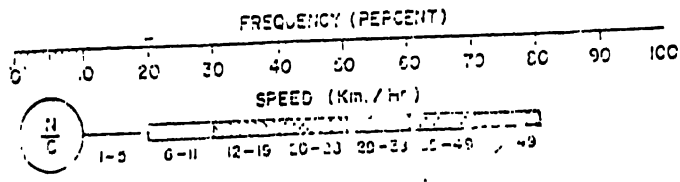
N_w - total frequency of the two lowest wind speed classes

n_w - the total frequency of the two lowest speed classes for a particular direction

Atmospheric stability

Atmospheric stability is the term applied to the condition of the atmosphere that affects the vertical motion of air parcels. Atmosphere is unstable when the vertical motion is enhanced. This condition occurs when temperature decreases with height at a rate higher than 0.98°C per 100 m. When the temperature lapse rate (rate of change of temperature with height) equals 0.98°C per 100 m, the atmosphere is said to be neutral and vertical motions are not affected. This lapse rate is called dry adiabatic lapse rate. When the temperature decreases with height at a rate less than the adiabatic or when temperature increases with height (temperature inversion) vertical motions are damped and the atmosphere is called stable. Intensity of turbulence and therefore the atmospheric diffusion increases with instability of the atmosphere, and decreases with increasing stability of the atmosphere. Atmospheric stability is controlled by insolation, nocturnal radiation loss and wind speed. The following studies have been conducted to formalize the relationships between atmospheric surface stability and the factors controlling stability i.e insolation, nocturnal radiation and wind speed.

Pasquill stability categories: A classification of stability in accordance with the wind speed and incoming solar radiation for day or cloud cover for night.

Brokhaven stability categories: A classification of stability in accordance with direction fluctuations.

Tennessee Valley Authority stability categories: A classification of stability in accordance with the temperature. Of the three, the Pasquill method is the most commonly used for the determination of stability class. The selection procedure is shown in Table 5.1.2. The stability classes in this system are:

Extremely unstable (A);
Moderately unstable (B);
Slightly unstable (C);
Neutral (D);
Slightly stable (E);
Moderately stable (F);
Extremely stable (G).

The basic parameters used for stability analysis are wind speed, insolation and cloudiness. Insolation is estimated by solar altitude. In Pasquill stability classes, "Moderate" insolation implies the amount of incoming solar radiation when sky is clear and solar elevation is between 35° and 60°. The term "strong" and "slight" insolation refer to solar elevation of more than 60° and less than 35° respectively. At night, estimates of outgoing radiation are made by considering cloud cover. Stability class D should be used for all overcast conditions during night or day regardless of wind speed.

Table 5.1.2. Pasquill stability classes

Surface wind speed (m/sec)	Daytime insolation			Night time condition	
	Strong	Moderate	Slight	Thick over-cast or <=4/8 cloud cover	>=3/8 cloud cover
2	A	A-B	B		
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
6	C	D	D	D	D

Mixing height (MH)

The height of the base of the inversion above the ground level is called mixing height. If vertical mixing is limited, pollutants emitted from a point source into the mixing layer will be trapped and, beyond some point downwind, will become uniformly mixed in the vertical. Mixing layer can be estimated by using a simple

model, where the temperatures at different elevations are known. The model assumes that the environmental lapse rate is a constant. Then,

$$H_m = \frac{T_{max} + C/m}{1/m - 1/m_1}$$

where,

$$C = \frac{T_1 Z_2 - Z_1 T_2}{T_1 - T_2}$$

and

$$m = \frac{Z_1 - Z_2}{T_1 - T_2}$$

where,

H_m - Afternoon mixing height, m

T_{max} - Maximum temperature of the day °C

T_1 & T_2 - Temperatures (°C) at height Z_1 and Z_2 respectively

m_1 - -100 (reciprocal of adiabatic lapse rate) in m/°C

Automodulated radiosondes gives the upper air temperatures at different elevations

Rainfall

Falling drops of precipitation pick up particulate matter and soluble gases vapours in their path This leads to depletion of pollutants from the atmosphere Washout leads to higher deposition rates of the pollutants on the ground than those obtained by dry deposition alone.

The depletion of concentration due to washout may be computed by multiplying the concentrations obtained from air quality model by the washout correction factor. Rainfall rate expressed in mm/h is measured by rain gauge apparatus.

5.2 Meteorological stations in the NCR

India Meteorological Department which was instituted in 1875, is recording and co-ordinating the observations of meteorological parameters, both at the surface and in the upper air, by maintaining observatories all over the country. Meteorological observatories are classified as

- Surface observatories
- Upper air observatories

· Radiation observatories

Surface observations

The climatological stations are broadly classified as under:

a) Categories I & I_o: This type of observatory is referred to as 'principal climatological station', taking at least 2 sets of synoptic observations a day. The synoptic hours are fixed at 0230, 0530, 0830, 1130, 1430, 1730, 2030, 2330 hours I.S.T. This observatory records pressure, temperature, wind (speed and direction) and rainfall.

b) Categories II to IV: These categories are designated as 'ordinary climatological station'. These are climatological stations at which observations are made at least once daily at fixed times of day including readings of extreme temperature and amount of precipitation.

c) Category V: The stations under this category are designated as precipitation stations. These stations record rainfall only once a day.

d) Category VI: The stations under this category are identified as 'climatological stations for specific purposes' and are not covered by the categories I to IV. These observatories are non-instrumental stations recording clouds, visibility, wind directions, and reporting the same by monthly registers.

Upper air observatories

Radiosonde observatories: At these observatories, observations of atmospheric pressure, temperature and humidity up to 20-25 km are made by balloon-borne radiosondes. This instrument contains a miniature radio transmitter, which is suitably modulated by changes in characteristics of three elements which respond to pressure, temperature and humidity respectively. When carried aloft by the balloon, the transmitter sends down radio signals which are recorded by suitable receiving ground equipment. These records provide data for computing the values of three meteorological elements.

Radiation observatories: The radiation stations are classified into three categories:

· Principal radiation station (p) make: (i) continuous measurements of global and diffuse solar radiation. (ii) measurement of duration of bright hours of sunshine.

· Ordinary radiation stations (O) making : (i) continuous measurement of global solar radiation (ii) measurement of duration of bright hours of sunshine.

· Other radiation stations record radiation parameters which does not fall into the above two categories.

Table 5.2.1 shows meteorological monitoring station in NCR, classified by type and class of observatory. There are 6 surface, 1 upper air and 1 solar radiation observatories, operational in NCR. Of the 6 surface observatories in the region, 1 is of class I, 4 of class II and 1 is of class III. Map 6 shows the meteorological stations in the region. Geographically one of the surface observatory is in Delhi, two each in Haryana and UP region, and one in Rajasthan region. Upper air and radiation observatories are located only in Delhi region. Thus, the availability of meteorological data in NCR is very limited. Also diurnal variation in meteorological parameters cannot be incorporated into air quality model (though it is essential) because of non-availability of data for different points of time in a day.

Inversion condition, an important condition which changes the concentration of pollutants drastically, is a very predominant phenomenon in North India. But there is only one upper air observatory in NCR i.e. at Delhi. Thus the limited meteorological information in NCR is a major lacuna in building the air quality status of this region.

Table 5.2.1. Meterological monitoring stations in NCR

State	Station	Class of observatory		
		Surface	Upper air	Radiation
Haryana and Delhi				
Delhi	New Delhi/ Safdarjung (A)	I	I	I
Gurgaon	Gurgaon	II		
Rohtak	Rohtak	II		
Uttar Pradesh				
Bulandshahr	Bulandshahr	II		
Meerut	Meerut	III		
Rajasthan				
Alwar	Alwar	II		

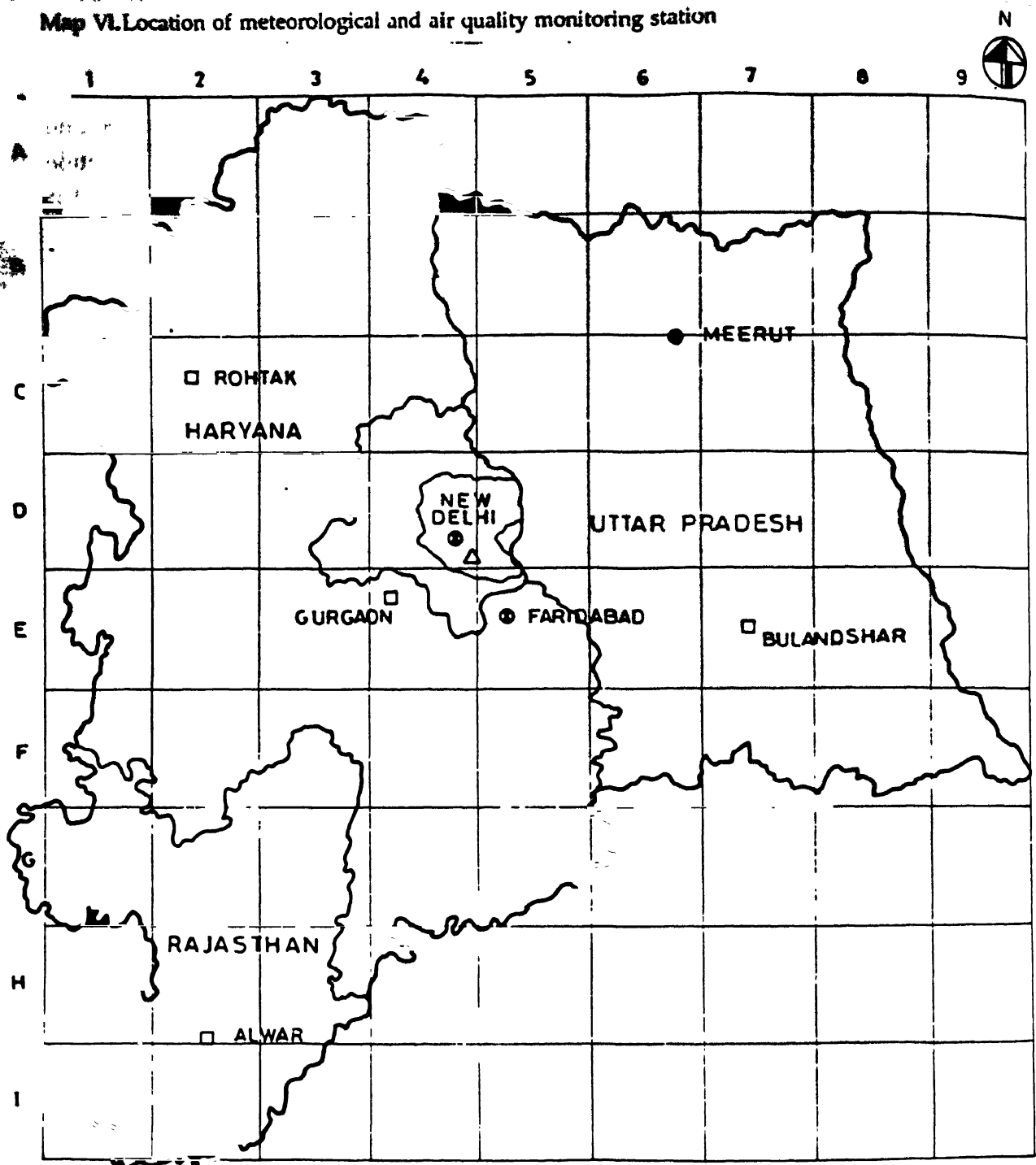
Map VI. Location of meteorological and air quality monitoring station

IMD Delhi was contacted to procure the data on the above said parameters. The data were not available for all the stations mentioned above. The daily wind speed data were obtained for the stations of Hissar, Karnal, New Delhi, Alwar and Jhalawar for the years 1988 and 1989. Only the stations at New Delhi and Alwar fall in the NCR. The data was classified and averaged for four seasons, namely winter (November-February), Pre-monsoon (March-June), Monsoon (July-August), and Post-monsoon (September-October). Table 5.2.2 shows the minimum, average and maximum wind speed data averaged for the years 1988 and 1989.

Table 5.2.2. Wind speeds for selected districts (m/s)

	Winter (Nov-Feb)	**Pre-monsoon (March-June)**	**Monsoon (July-August)**	**Post-monsoon (September-October)**
Average wind speed				
Hissar	1.5	3.3	2.6	2.4
Karnal	1.9	4.1	4.5	2.1
New Delhi	2.8	4.4	4.7	1.1
Alwar	0.5	1.6	1.3	0.8
Jailor	1.8	2.0	4.2	1.6
Minimum wind speed				
Hissar	n	n	n	n
Karnal	n	n	n	n
New Delhi	n	n	0.5	n
Alwar	n	n	n	n
Jailor	n	n	n	n
Maximum wind speed				
	7.3	21.0	11.0	36.5
Hissar	8.8	12.0	45.0	32.4
Karnal	26.0	14.3	14.0	5.7
New Delhi	2.0	12.5	5.5	2.1
Alwar	5.3	12.3	18.5	6.1
Jhalawar				

Because of inadequate data available from the IMD, information is also compiled from the secondary sources. Padmanabha Murty (Padmanabha Murty et al, 1988) have analyzed meteorological data of representative five years (1980-1984). Table 5.2.3

shows the predominant wind direction, stability class and mixing height for each of the season.

Table 5.2.3. Predominant wind directions

Season	Day (D) Night (N)	Direction
Winter	D	WNW-N
	N	WNW-N
Pre-monsoon	D	NW-W
	N	NW-N
Monsoon	D	E-SE
	N	E-SE
Post-monsoon	D	WNW-N
	N	WNW-N

Table 5.2.4. Pasquill stability classes

	Percentage frequency							
	Day				Night			
Season	A	B	C	D	D	E	F	G
Winter	0	12	20	18	4	2	10	34
Pre-monsoon	5	16	18	11	5	4	13	28
Monsoon	4	9	17	20	7	5	24	14
Post-monsoon	4	23	11	10	1	2	6	41

Table 5.2.5. Mixing height for four season of Delhi

Season	Minimum (m)	Maximum (m)
Winter	250	1960
Pre-monsoon	375	3580
Monsoon	345	1560
Post-monsoon	260	2840

Chapter 6

Air quality

The quality of air can be described meaningfully with the help of ambient concentration levels of different pollutants. Concentration is a measure of the average density of pollutants usually specified in terms of pollutant mass per unit volume of air typically in units of micro grams per cubic meter ($\mu g/m^3$) or in terms of relative volume of pollutant per unit volume of air (ppm).

6.1 Air quality standards

The Central Pollution Control Board (CPCB) has laid down air quality standards in the year 1982. The standards are different for the type of geographical area. Geographical areas were categorized into three classes viz. Industrial and mixed use (I), Residential and rural (R) and Sensitive (S) which includes hill stations, national parks and monuments. Table shows the 8-hourly average standards for each pollutant type. The concentrations for the prescribed pollutants should be 95% of the times within the prescribed limits given in the table.

Table 6.1.1. Ambient air quality standards ($\mu g/m^3$)

Category	SPM	SO_2	CO	NO_2
Industrial and mixed area	500	120	5000	120
Residential and rural	200	80	2000	80
Sensitive	100	30	1000	30

Source. GOI, 1990

The above air quality standards have been reviewed recently and the proposed air quality standards for the relevant parameters are given in the table. The proposed air quality standards have been prescribed for the annual, 24-hourly and hourly average values.

Table 6.1.2. Proposed national ambient air quality standards

Pollutant	Averaging time	Concentration (micro gms per cu mt)	
		General	Sensitive
SO_2	Annual avg	80 (0.03 ppm)	30
	24 hrs	130 (0.05 ppm)	30
	1 hr	655 (0.25 ppm)	
NO_2	Annual avg	100 (0.053 ppm)	30
	24 hrs	200 (0.106 ppm)	30
	1 hr	470 (0.250 ppm)	
SPM	Annual avg	200 (400)#	100 (200)#
	24 hrs	400 (800)#	200 (400)#

Source: GOI, 1990

Not more than 2% of the total number of observations in a year should exceed the figures presented within the brackets for SPM

6.2 Air quality status in the National Capital Region

The Central Pollution Control Board (CPCB) under the programme "National Ambient Air Quality Monitoring (NAAQM)" has monitored the pollutants namely sulphur dioxide (SO_2), nitrogen dioxide (NO_2) and suspended particulate matter (SPM). Delhi and Faridabad are the two areas in the NCR for which the ambient air quality data is available. Map 5 shows the air quality monitoring stations in the region.

Union Territory of Delhi: There are six NAAQM locations in the Delhi region. They are:

1) Ashok Vihar
2) Janak Puri
3) Nizamuddin
4) Shahdara
5) Shahzada Bagh
6) Siri Fort

Tables 6.2.1 to 6.2.8 show the minimum, mean, and maximum monthly and annual average for the year 1989. The annual and 24-hourly mean values for sulphur dioxide and nitrogen dioxide did not exceed the stipulated standards during the year 1989. The 98-percentile values for SPM exceeded the prescribed standard of 800 $\mu g/m^3$ at Ashok Vihar, Shahzada Bagh and Shahdra, Whereas the annual mean values and the 90-percentile values for SPM exceeded 200 $\mu g/m^3$ and 400 $\mu g/m^3$ respectively at all the locations.

Table 6.2.2. Ambient air quality: Delhi (Location - Ashok Vihar) ($\mu g/m^3$)

Month	Sulphur dioxide				Nitrogen dioxide				Particulate matter			
	Min	Mean	Max.	n	Min.	Mean	Max.	n	Min.	Mean	Max.	n
Jan	3.2	7.0	20.5	6	4.2	24.3	47.0	6	186	306	460	6
Feb	3.0	8.1	20.2	7	3.5	17.7	34.2	7	144	379	626	9
Mar	3.0	3.2	3.5	9	10.6	27	35.2	8	190	299	544	10
Apr	3.0	3.2	3.7	10	26.2	31.6	38.2	10	198	381	810	10
May	3.2	4.5	7.0	7	22.4	25.1	32.2	7	311	572	1244	7
Jun	3.2	9.7	24.8	9	15.2	25.1	36.8	9	204	610	1462	10
Jul	3.0	5.2	9.5	9	12.0	22.6	32.2	9	126	321	831	9
Aug	3.2	4.9	7.0	9	17.5	26.4	44.4	9	100	199	442	10
Sep	3.0	4.3	8.0	10	10.7	17.6	22.8	10	124	253	410	11
Oct	3.0	5.2	7.2	9	7.8	20.2	33.8	9	204	454	771	10
Nov	3.0	3.1	3.5	7	15.8	22.6	41.2	7	226	442	791	9
Dec	3.0	3.1	3.5	10	11.2	19.5	28.5	9	356	429	717	10
Ann	3.0	5.0	24.8	102	3.5	23.4	47.0	100	100	385	1462	111

n - number of > = 16 hours monitored days

BDL - below detection level

Table 6.2.3. Ambient air quality: Delhi (Location - Shahzada Bagh) ($\mu g/m^3$)

Month	Sulphur dioxide				Nitrogen dioxide				Particulate matter			
	Min.	Mean	Max.	n	Min.	Mean	Max.	n	Min.	Mean	Max.	n
Jan	8.5	17.5	39.2	10	15.0	22.1	38.0	10	192	362	493	10
Feb	17.5	26.3	44.4	9	12.0	33.1	50.3	8	344	513	649	10
Mar	3.4	16.5	46.7	9	13.7	33.9	78.2	9	272	509	798	10
Apr	3.5	6.0	13.0	9	5.2	11.4	16.2	9	339	500	769	9
May	3.0	6.1	12.4	8	9.0	18.0	28.0	8	364	742	1932	9
Jun	5.4	7.9	12.2	10	10.0	14.2	24.8	10	216	673	1840	10
Jul	3.0	3.2	4.8	9	13.2	27.3	50.0	9	270	528	1106	10
Aug	3.5	17.1	41.0	8	4.5	21.8	57.2	8	174	316	487	9
Sep	3.2	3.8	5.0	10	5.6	11.6	18.0	10	174	367	509	11
Oct	6.8	8.0	9.2	9	16.7	22.0	26.2	9	366	469	622	9
Nov	3.0	3.6	4.8	8	15.8	19.7	23.2	8	303	493	655	8
Dec	3.0	3.7	5.0	10	16.2	21.8	29.3	10	165	654	1292	10
Ann	3.0	9.9	46.7	109	4.5	21.2	78.2	108	165	510	1932	115

n - number of > = 16 hours monitored days

BDL - below detection level

Table 6.2.4. Ambient air quality: Delhi (Location - Shahdra) ($\mu g/m^3$)

Month	Sulphur dioxide				Nitrogen dioxide				Particulate matter			
	Min.	Mean	Max.	n	Min.	Mean	Max.	n	Min.	Mean	Max.	n
Jan	5	11.5	21.2	9	7.2	29.8	58.0	9	159	263	416	10
Feb	8	19.6	28.2	9	13.8	19.1	23.5	9	202	311	476	9
Mar	11.8	18.9	30.5	9	9.2	17.6	22.2	9	126	281	449	10
Apr	7	12.8	21.8	10	8.5	15.1	22.5	10	197	319	466	10
May	10.5	15.5	22.8	8	8.0	11.9	16.2	8	242	634	1722	9
Jun	6.8	10.2	14.8	10	3.8	11.0	15.5	10	214	460	1174	10
Jul	3.8	9.5	15.5	11	8	15.0	22.0	11	198	387	771	11
Aug	7.8	16.6	30	9	11.8	20.0	27.2	9	92	260	462	9
Sep	4	9	14.8	11	4	6.1	9	11	226	306	352	10
Oct	12.2	15.6	18	10	11.2	15.2	17.2	10	328	443	602	10
Nov	5.5	-	9.5	9	5.5	8	11.2	9	214	364	[illegible]	10
Dec	12.8	18.4	27	8	13	20.3	28.5	8	127	315	510	10
Ann	3.8	13.5	30.5	113	3.8	15.5	58.0	113	92	361	1722	118

n - number of > = 16 hours monitored days

BDL - below detection level

Table 6.2.5. Ambient air quality: Delhi (Location - Janak Puri) ($\mu g/m^3$)

Month	Sulphur dioxide				Nitrogen dioxide				Particulate matter			
	Min.	Mean	Max.	n	Min.	Mean	Max.	n	Min.	Mean	Max.	n
Jan	6	10.1	17.5	7	17.5	26.2	43.2	7	66	258	560	9
Feb	3	3.8	6.5	10	6.5	14.9	29.5	10	127	251	362	10
Mar	3.2	6.7	13.2	8	25.0	28.7	35.2	7	172	264	415	10
Apr	5	12.9	27	8	23.5	33.2	45.8	8	198	337	516	9
May	7.5	9	12.2	8	17.2	23.8	34.2	8	351	546	1088	8
Jun	4.8	7.9	13.2	5	25	34.5	45.2	5	354	402	428	5
Jul	3	5.4	14.2	5	3	4.7	8.5	5	109	264	554	-
Aug	3	4.2	5.2	9	4.2	7	12	9	96	294	968	9
Sep	3	4.1	7.8	7	3	6.4	10.8	7	136	250	482	11
Oct	3	3.6	5.2	6	3.2	3.5	18.2	6	328	430	686	10
Nov	3	3	3.2	5	12	19.9	20.8	5	202	296	351	7
Dec	3	3	3	7	3.2	12.9	28.5	7	196	329	649	9
Ann	3	6.2	37.0	85	3	18.3	35.8	84	66	322	1088	104

n - number of >= 16 hours monitored days

BDL - below detection level

Table 6.2.6. Ambient air quality: Delhi (Location - Siri Fort) ($\mu g/m^3$)

Month	Sulphur dioxide				Nitrogen dioxide				Particulate matter			
	Min.	Mean	Max.	n	Min.	Mean	Max.	n	Min.	Mean	Max.	n
Jan	3	3.9	7	7	16.8	23.6	30.5	7	166	279	420	7
Feb	3	3.4	4.8	9	5.2	12.7	19.8	9	226	368	512	10
Mar	3	3.3	5.2	9	9.5	15.8	26.8	8	111	235	379	9
Apr	3	3.9	7.5	8	9.8	15.9	21.8	8	171	384	893	10
May	3	6.9	11.8	6	7.5	15.1	23.5	6	252	526	1308	7
Jun	3	8.5	15.5	9	9.2	14.2	20.2	9	172	494	1086	9
Jul	3	8.9	15.8	9	12.5	17.4	26.2	9	118	308	638	9
Aug	3	3	3	7	5.8	9.9	17.4	7	76	179	408	9
Sep	3	3.5	4.8	7	7.8	13.2	21.8	7	72	202	328	9
Oct	3	4.3	7.2	8	9.2	15.8	20.5	8	192	361	580	10
Nov	3	3.4	4.2	6	11.5	13.8	18	6	156	279	488	7
Dec	3	3	3.2	5	9.2	12.7	15.8	5	139	327	475	9
Ann	3	4.8	15.8	90	5.2	15.1	30.5	89	72	328	1308	105

n - number of > = 16 hours monitored days

BDL - below detection level

Table 6.2.7. Ambient air quality: Haryana, Faridabad (Location - Escorts Medical Centre) ($\mu g/m^3$)

Month	Sulphur dioxide				Nitrogen dioxide				Particulate matter			
	Min.	Mean	Max.	n	Min.	Mean	Max.	n	Min.	Mean	Max.	n
Jan	23.9	25.6	27.4	12	6.7	7.7	9.1	12	157	204	270	12
Feb	23.7	25.1	27.7	12	6.7	8.6	10.2	12	227	279	363	12
Mar	22.7	24.9	26.7	11	4.7	7.4	9.8	11	239	292	322	11
Apr	17.2	20.3	25.0	11	6.0	9.0	11.8	11	265	314	355	11
May	24	27.1	30.2	13	9.3	15.8	18.2	13	282	303	327	13
Jun	24.2	29	35.5	11	10.7	15.2	18.3	11	313	392	415	11
Jul	33.5	35.6	37.7	12	9	11.8	26.8	12	242	267	293	12
Aug	36.8	38.1	39.3	12	7.7	9.7	11.5	12	212	241	270	12
Sep	33.8	35.6	37.7	12	11.5	14.2	16.2	12	215	263	315	12
Oct	33	35.9	38.2	12	15.3	16.7	19.3	12	306	326	339	12
Nov	32.7	36	36.8	12	13.3	16.5	19.2	12	226	250	268	12
Dec	32.3	35.1	37.6	11	13.3	15.1	17.5	11	229	246	269	11
Ann	17.2	30.8	39.3	141	4.7	12.4	26.8	141	157	281	415	141

n - number of > = 16 hours monitored days

BDL - below detection level

Table 6.2.8. Ambient air quality : Haryana, Faridabad (Location - R.C. Kothi No. 63, Sector 9) ($\mu g/m^3$)

Month	Sulphur dioxide				Nitrogen dioxide				Particulate matter			
	Min.	Mean	Max.	n	Min.	Mean	Max.	n	Min.	Mean	Max.	n
Jan	23.5	25.6	28.1	12	6.8	8.4	9.8	12	139	198	256	12
Mar	22.7	24.6	26.7	12	8.0	10.7	12.8	12	220	279	357	12
Apr	16.7	21.0	25.2	12	7.0	8.4	12.0	12	268	311	337	12
May	26.7	28.6	31.2	12	11.2	14.8	18.3	12	291	314	357	12
Jun	24.5	28.5	39.3	12	13.8	16.6	20.0	12	390	404	425	12
Jul	34.0	37.1	39.3	12	8.8	10.5	11.8	12	198	241	306	12
Aug	36.8	38.2	39.5	11	9.0	10.2	11.7	11	176	225	253	11
Sep	33.2	35.3	36.7	12	10.2	14.1	17.3	12	186	236	289	12
Oct	33.0	26.1	27.8	12	13.3	16.2	19.0	12	294	328	353	12
Nov	33.8	35.9	38.3	12	13.8	16.1	18.8	12	234	254	269	12
Dec	32.2	33.8	35.5	12	11.2	12.7	14.3	12	213	232	257	12
Ann	16.7	31.3	39.5	131	6.8	12.6	20.0	131	139	275	425	131

n - number of > = 16 hours monitored days

BDL - below detection level

Chapter 7

Description of models

The inventory of sources of pollution in the NCR comprised point,line and area sources. The relationship of pollutant emissions to air pollution concentrations is most effectively established through the use of an atmospheric dispersion model, based on quantitative description of the transport and dispersion of pollutants in the atmosphere. There are many kinds of dispersion models varying in complexity and utility. Gaussian plume models are widely used and recommended models. These type of models have been in operational use for a considerable period of time, and are still being used with success where they are approximately applied. The basic models for each category of sources to predict air quality are described below. Various assumptions made in using the models to predict the air quality in the NCR are also mentioned.

7.1 Gaussian dispersion air quality model for point source

Basic Principle

The emissions from stationary sources are subjected to a) an initial vertical rise called plume rise due to initial buoyancy and momentum of discharge, b) transport of pollutants by wind in its direction, and c) diffusion of pollutants by turbulence.

Assumptions in the Gaussian model

a) Steady state conditions, ideal gas, continuous uniform emission rate, homogeneous horizontal wind field, representative mean wind velocity, no directional wind shear in the vertical plane and infinite plume.

b) Total reflection of the plume taking place at the earth's surface.

c) Gaussian distribution, i.e. the pollutant material within the plume assumes a Gaussian distribution in both horizontal cross wind and vertical directions

Basic equation

Concentration of a pollutant in air due to its release into the atmosphere from a single continuous point source is calculated by Pasquill's equation modified by Gifford as follows: .

$$C(x,y,z) = \frac{Q}{2\pi\ \sigma y\ \sigma z\ U} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma y}\right)^2\right] \left[\exp\left\{-\frac{1}{2}\left(\frac{z-H}{\sigma z}\right)^2\right\} + \exp\left\{-\frac{1}{2}\left(\frac{z+H}{\sigma y}\right)^2\right\}\right] \quad ...7.1.1$$

where,

C(x,y,z) - concentration of the pollutant at receptor point x, y, z from a continuous source, g/m3

Q - emission rate of pollutant, g/s

u - wind velocity along the x direction at stack height hs, m/s

y - cross wind distance, m

x - down wind distance, m

z - vertical height, m

σy - horizontal dispersion coefficient, m

σz - vertical dispersion coefficient, m

hs - stack height, m

ds - plume rise, m

H - effective stack height (hs+ds), m

Following sections describe the dispersion coefficient, wind scaling correction, plume rise and stack downwash which are components of the model.

Dispersion coefficients

Dispersion coefficients σy and σz are standard deviations of distributions of concentrations in horizontal cross wind and vertical directions respectively. These are dependent on the atmospheric stability and the downwind distance. The quantities σy and σz increase with increasing downwind distance x, signifying that the dilution increases with distance. The rate at which σy and σz increase will depend upon the turbulence intensity, and hence stability of the atmosphere. There are three models in use for estimation of dispersion coefficients. They are Pasquill-Giffords (PG), Tennessee Valley Authority (TVA), and American Society of Mechanical Engineers (ASME). In the present study, ASME model is used for estimation of dispersion coefficients. This model has four stability classifications, namely a) very unstable, b) unstable, c) neutral, and d) stable.

The standard deviations σy and σz are given in terms of power law:

$$\sigma y = a x^{p}$$

$$\sigma z = b x^{q}$$

Table 7.1.1 gives the values of a,b,p,q for these four cases.The averaging time for dispersion coefficients in ASME method is one hour.

Table 7.1.1. Values of a, b, p and q in the ASME Model

Stability	a	b	p	q
Very unstable (A, B)	0.40	0.91	0.40	0.91
Unstable (C)	0.36	0.86	0.36	0.86
Neutral (D)	0.32	0.78	0.22	0.78
Stable (E, F)	0.31	0.71	0.06	0.71

Note: The letters in the parenthesis correspond to the PG stability classification.

Scaling of wind speed (wind speed at stack height)

In the layer of the atmosphere above the ground, wind speed changes with the height. Generally it increases with height, but is highly dependent upon the stability condition of the atmosphere. The wind speed at the stack height was computed based on the following power law:

$$U_1 = U_2(z_1/z_2)^p$$

where,

U_1 - wind speed at height z_1 above msl, m/s

U_2 - wind speed at height z_2 above msl, m/s

z_1 - stack height, m

z_2 - elevation of meteorological station above msl, m

p - wind profile exponent

The exponent p is dependent on atmospheric stability and has a value between 0 to 1. Table 7.1.2 shows recommended values of exponent p.

Table 7.1.2. Wind speed profile exponent as a function of stability

PG stability class	A	B	C	D	E	F
p	0.15	0.17	0.20	0.26	0.39	0.48

A - extremely unstable, B - moderately unstable,

C - slightly unstable, D - neutral,

E - slightly stable, F - moderately stable

Plume rise

Plume rise, which is measured by the elevation of the plume centre line above the stack outlet, depends upon the initial flux of momentum (exit velocity) and heat passing through the stack exit. There are over 20 plume rise equations that have appeared in the literature and new ones are being proposed. For this study, the plume rise equation recommended by Bureau of Indian Standards (ISI, 1978) is used.

$$Q_h = Q_m(T_s - T_a)C_p$$

$$\text{for } Q_h \geq 10^6 \text{ cal/sec}$$

$$dh = 0.84 * (12.4 + 0.09hs) * Q_h^{0.25}/U$$

otherwise,

$$dh = 3\ v_e\ D/U$$

where,

Q_h - heat output at the stack, cal/sec,

Q_m - emission rate, g/sec

T_s - efflux temperature, °K

T_a - ambient temperature, °K

C_p - specific heat, cal/g °K

C_p - 0.255 for oil, 0.265 for natural gas, and 0.255 for coal

hs - physical height of the stack, m

U - wind speed at stack height, m/s

v_e - efflux velocity, m/s

D - stack diameter, m

dh - plume rise, m

Stack downwash

When a plume meets an obstacle (natural or manmade), the obstacle causes a separation of flow around it, and generates turbulence in the wake, thus forming a cavity behind the obstacle, and pollutants gets entrained into this cavity causing high concentrations. Such an effect is called stack downwash. Downwash of plume into the low pressure region in the wake of a stack can occur if the efflux velocity is too low. The effect of stack downwash is incorporated through a modified expression for the plume rise by multiplying a factor 'f' to the plume rise. For this study, downwash correction factor f with computed as per the guidelines by Cramer et al (Patil S.B, 1984).

$$f = 1 \quad \text{if } u \le v_e/1.5$$

$$f = 3 \times v_e - u/v_e \quad \text{if } v_e/1.5 \le u < v_e$$

$$f = 0 \quad \text{if } u \ge v_e$$

where,

v_e - efflux velocity in m/sec

u - wind speed at stack height.

The calculated plume rise, dh, is multiplied by this factor and is used in the dispersion equation 7.1.1 for estimating concentration, i.e. ds = f * dh

Rain washout

Falling drops of precipitation pick up particulate matter and soluble gases vapours in their path. This leads to depletion of pollutants from the atmosphere. Washout leads to higher deposition rates of the pollutants on the ground than those obtaining by dry deposition alone. The depletion of concentration owing to washout may be computed by multiplying the concentrations obtained from air quality model by the washout correction factor (FR).

$$FR = \exp\left[\frac{-\Omega x}{u}\right]$$

where,

$$\Omega = 5.9 * 10^{-4} Y . r^{0.59} (S^{-1})$$

Ω - rain washout coefficient

Y - molecular diffusivity in cm^2/sec of the gas

r - rainfall rate in mm/n

However, this correction is not applied in this study.

Short term concentrations

The short-term concentrations are estimated by equation 7.1.1. For concentrations calculated at ground level i.e. z = 0 and at plume centre line i.e. y=0, the expression becomes

$$C(x,0,0) = \frac{Q}{\pi\, \sigma y\, \sigma z\, u} \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma z}\right)^2\right]$$

The distance at which maximum concentration occurs is

$$X_{max} = \left[\frac{H^2 q}{(b+q)p^2}\right]^{1/2q}$$

where b, p, q are parameters associated with the dispersion coefficients.

The maximum ground level concentration is given by

$$(GLC)_{max} = C(X_{max},0,0) = \frac{Q}{\pi\ \sigma y_{max}\ \sigma z_{max}\ u} \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma z_{max}}\right)^2\right]$$

The point where the plume boundary (defined as the locii of all points where the concentration has dropped to 10% of the concentration at the centre line) touches the ground is given by the equation :

$$X_g = \left[\frac{H}{2.4477p}\right]^{1/q}$$

Long term averaging

Long term (seasonal, annual) concentration averages of various pollutants are needed to evaluate the effectiveness of air pollution control strategies or to ascertain the impact of projected industrial or residential growth in compliance with ambient air quality standards. The meteorological factors used to calculate concentrations are the wind speed, wind direction, and stability class. If there are N wind speed classes, S stability classes and Θ wind directions, then long-term average concentration at a distance x in wind direction Θ is given by

$$C(x,\theta) = \sqrt{2/\pi}\ \frac{Q}{100(2\pi x/\theta)} \sum_N \sum_S \frac{f(\theta,S,N)}{U_n\ \sigma_{zs}} \exp\left[-\frac{1}{2}\ \frac{H^2}{\sigma^2_{zs}}\right]$$

...7.1.2

where,

f(Θ,S,N) - the percentage frequency during the period of interest that the wind is from the direction Θ, for the stability condition S and the wind speed class N.

U_n - mid value of the wind speed of class N

σ_{zs} - vertical dispersion coefficient corresponding to stability class S.

Θ - is the wind direction

For the case of limited mixing layer or trapping, the following equation applies to distances equivalent to or beyond certain distance xtb (Stern, 1987). xtb is the distance at which the edge of the reflected plume reaches the ground level. At this

location and beyond, the concentration distribution is assumed to be uniform in horizontal and vertical direction i.e. the box model concept:

$$C(x,\theta) = \frac{Q * f(\theta,S,N)}{H_m\, U_a\, (2 * \pi\, x/\theta)}$$

where,

H_m - height of the stable layer under which trapping occurs, m

Worst possible scenarios

The worst case is useful in identifying the greatest impact that will occur in a given year. Trapping and fumigation are the two worst cases of atmospheric conditions which can lead to episodic conditions.

Trapping: Plume trapping occurs when the plume is trapped between the ground surface and a stable layer aloft (increase). The following equation is used in estimating the concentrations under trapping condition:

$$C_t(x,y,z,H) = \frac{Q}{2\pi u\ \sigma y\ \sigma z\ u} \exp\left[\frac{-y^2}{2\sigma y^2}\right] s\left[\frac{Z}{\sigma z}, \frac{H}{\sigma z}, \frac{Hm}{\sigma z}\right]$$

where,

$$s\left[\frac{Z}{\sigma z}, \frac{H}{\sigma z}, \frac{Hm}{\sigma z}\right] = \sum_J \left[\exp\left(\frac{-(Z + 2JHm - H)^2}{2\ \sigma z^2}\right) + \exp\left(\frac{-(Z + 2JHm + H)^2}{2\ \sigma z^2}\right)\right] \quad \text{... 7.1.3}$$

with J = 0, 1, 2, ...

where, Hm is the height of mixing layer, m

The summation of infinite series can be terminated for n = 5 which is reported to be adequate (Turner, 1970). This equation accounts for multiple eddy reflections from both the ground and the stable layer.

Fumigation: When the ground is being warmed by solar radiation or when air flows from a cold to a relatively warm surface, a surface-based inversion may be eliminated by the upward transfer of sensible heat from the ground surface. This situation usually occurs for a short duration at mid-morning. Under such conditions pollutants previously emitted above the surface into a stable layer will be mixed downward vertically when they are reached by the thermal eddies, and ground level concentrations can become very high. This process is described as fumigation. To estimate ground level concentrations under inversion break-up fumigations, one assumes that the plume was initially emitted into a stable layer. Therefore σy and σz characteristic of stable conditions must be selected for the particular distance of

concern. An expression for ground level concentration is given below:

$$C(x,0,0) = \frac{Q}{1.1\sqrt{2\pi}\,\sigma yf\ Hf\ U}$$

where,

$$\sigma yf = \sigma y + 0.47H$$

and

$$Hf = H + 2.15\ \sigma z$$

Averaging time calibration

Concentrations obtained by using the values of ASME dispersion coefficients would be valid only for the one hour sampling time for which σy and σz are also valid. To convert one hour sampling time to eight hour sampling time, the following power law function of time ratio is used:

$$c_8/c_1 = (t_1/t_8)^{\alpha}$$

B.I.S has suggested a value of 0.4 for α. Such a relationship is valid in the range of 3 minutes to 24 hours.

7.2 Simple line-source model for vehicle exhaust dispersion near a road (GM model)

The model was constructed based on the findings of the General Motors Sulphate Dispersion Experiment. Because of the infinite line-source assumption, the model is applicable to a situation where the upwind segment of the road (measured from the perpendicular line drawn from the receptor) is at least three times the distance between the receptor and the road. The vertical dispersion parameters are functions of distance from a lane to the receptor, and of the wind direction relative to the road.

Model formulation

The concentration C at a point (x,z) relative to the line is described by

$$C(x,z) = \frac{Q_l}{\sqrt{2\pi}\, U\, \sigma_z}\left\{\exp\left[-\frac{1}{2}\left(\frac{z+h_o}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{z-h_o}{\sigma_z}\right)^2\right]\right\}$$

..7.2.1

where,

$C(x,z)$ - concentration, g/m^3

Q_l - emission rate per unit length, g/m/s

U - effective crossroad wind component, m/s

σz - vertical dispersion parameter, m

x - distance from the receptor to the line source, m

z - height of the receptor relative to the line source, m

h_o - plume centre height relative to the ground, m

The effective crossroad wind component is

$$U = U_a + U_o$$

where,

U_a is the component of the ambient wind which is perpendicular to the road. Thus one must multiply the ambient wind speed by sin Θ (Θ is the angle between the ambient wind and the road) to obtain U_a. U_o is the wind speed correction whose values are given in the Table 7.2.1.

The vertical dispersion parameter is described by

$$\sigma z = (a + bf(\theta)x)^c$$

where,

$$f(\theta) = 1 + \beta \left|\frac{\theta - 90^o}{90^o}\right|^\gamma$$

The values of a, b, c, ß and gamma are provided in Table 7.2.1. The plume centre height is

$$h_o = z_o + h_p$$

where z_o is the line-source height and hp, the plume-rise , is

$$h_p = \left(\frac{F_1}{\alpha U'^3}\right)^{1/2} X$$

F_1 is the buoyancy flux (m^3/sec^3), U'= Ua+U1 while α and U1 are given in Table 7.2.1.

In the above equation, the buoyancy flux is calculated by

$$F_1 = \frac{g}{T_o C_p} x Q_m$$

where,

F_1 - buoyancy flux, m^2s^{-3}

T_o - the ambient air temperature and

g - acceleration due to gravity, m/s^2

C_p - the specific heat (at constant pressure) of air (=3.08 x 10^2 cal.m $l^{-3}k^{-1}$)

Q_m - heat emission rate per unit length, $cal.m^{-1}.s^{-1}$

The heat emission rate was determined in the General Motors Sulphate Dispersion Experiment (465 $cal.m^{-1}.s^{-1}$) based on the temperature and trace gas data.

Should it be inconvenient to determine F_1, an estimate would be to use the heat emission rate of 465 $cal.m.^{-1}.s^{-1}$, divide it by the traffic density per lane of 1365 veh/h (from the GMS experiment), and then multiply by the traffic density per lane of interest. The resulting heat emission rate can then be used to determine F_1 according to equation given above.Since the experiments were carried out at 4.5 m height, the wind speed used in the model should be scaled down above the ground.

Table 7.2.1. The parameters used in the model

	Stable	Neutral	Unstable
a (in m^{1-c})	1.49	1.14	1.14
b (in m^{-1+c})	0.15	0.10	0.05
c	0.77	0.97	1.33
beta	5.82	3.46	3.46
gamma	3.57	3.50	3.50
alpha	20.7	11.1	11.1
U1(in m/s)	0.18	0.27	0.27
U_o(in m/s)	0.23	0.38	0.63

7.3 Area source model

In the present study, simple and realistic source oriented Atmospheric Turbulence and Diffusion Laboratory (ATDL) model was used to estimate the long term surface concentration of pollutants due to low level emissions. The model can be applied satisfactorily for regions where emissions are at low level - such as the emissions from domestic , commercial, transport and low level industrial pockets - and are uniformly distributed over the region.

Gifford's "reciprocal plume" concept is employed in order to estimate the surface concentration C due to area source upwind of the receptor point. The contribution of the grid block in which the receptor is located and four additional grid blocks upwind of the central grid are considered.

The surface concentration C of a pollutant resulting from to emissions from an area source is a function of the distribution of area source strength, wind speed, and direction and the atmospheric stability. The area source distribution is assumed to be relatively smooth. This assumption permits us to neglect the horizontal cross wind components to the diffusion in comparison with the vertical components.

According to Gifford (Hanna S.R., 1972), the surface concentration C at the receptor point can be computed:

$$C = \int_0^x \sqrt{\frac{2}{\pi}} \frac{Q_a}{U\sigma_z} dx$$

...7.3.1

where,

C - surface concentration of the pollutant, g/m^3

Q_a - source strength, $g/m^2 s$

Δx - distance to the edge of the urban area, m

U - wind speed, m/s

σz - vertical dispersion parameter, m

The vertical distribution of the pollutants is assumed to be Gaussian or normal, with standard deviation σz. Smith (Hanna S.R., 1972) suggests the following relationship for σz.

$$\sigma_z = ax^b$$

where,

a and b are the constants which depend upon the stability of the atmosphere.

x - distance, m

Table 7.3.1. Dispersion coefficients

Sunny day	a=0.40	b=0.91
Cloudy day	a=0.15	b=0.75
Night	a=0.06	b=0.71

If the receptor is at the centre of grid block 'o', with grid distance Δx, and the wind blows in only one direction, the equation 7.3.1 can be written as the summation over grid squares upwind of the receptor square:

$$C = \sqrt{\frac{2}{\pi}} \frac{(\Delta x/2)^{1-b}}{U_a(1-b)} \left[Q_{AO} + \sum_{i=1}^{4} Q_{Ai} \left\{(2i+1)^{1-b} - (2i-1)^{1-b}\right\} \right]$$

The source strengths Qa0, Qa1, Qa2, apply to the grid square in which the receptor is located, the grid square upwind of the receptor square, and so on respectively. The relative weight of source strengths for grid blocks 0, 1, 2, 3 is 1, 0.31, 0.19, 0.13, 0.10, when b = 0.75 for neutral stability. For N =4, to, four, summation of the constants outside of central grid block is, thus, more heavily weighted than the strengths of other blocks combined.

A simplified version of the model is derived from the assumption that the main contribution to the concentration of pollutants is only from the central grid, and the contribution from other grids can be neglected. Hence the expression reduces to

$$C = \sqrt{\frac{2}{\pi}} \frac{(\Delta x/2)^{1-b}}{Ua(1-b)} Q_{AO}$$

Chapter 8

Air quality predictions in the National Capital Region

To estimate the desired reduction of pollution or to define the tolerance levels of a geographical area for receiving additional pollution from new developments, it is essential to translate pollution emission from different sources into pollution concentrations in a given area. The ambient concentrations of pollutants at ground level is an important indicator of the level of pollution. Such concentrations of pollutants not only depend on the rate of emissions but also on the meteorological variables such as wind speed and stability conditions. This is described by an atmospheric dispersion model, which considers quantitative descriptions of the transport and dispersion of pollutants in the atmosphere. In the present study, TERI has adopted a set of air quality models (described in Chapter 7) to predict the concentrations for point, line and area sources for a given input of wind speed, wind direction, source emission rate and atmospheric stability conditions.

8.1 Concentration profile due to vehicular movement on corridors

Line source model developed by TERI was used to estimate the emissions across corridors. This model is based on General Motor (GM) model algorithm. Amongst all the models which are available, the GM model was chosen as it was found to be most suitable from the point of view of data availability. This is the most detailed and well validated line source model available. GM model has the highest correlation with observed concentration for all road-wind angles and stability conditions (Chock, 1977). The salient features of the TERI model are:

- The algorithm are based on GM model assumptions.
- Model predicts the ground level concentrations (GLCs) short term as well as long term concentration.
- The modal takes into account road-wind angle and turbulence due to traffic wake by adjustment of dispersion coefficient in z direction.
- The model considers plume rise over the roadway.

As the meterological data was not elaborate, three wind speeds were considered (0.7 m/s, 2.1 m/s, 4.2 m/s) to represent the range of minimum, average and maximum speeds. The road-wind angle is considered as 90° This angle gives the maximum concentration levels vis a vis any other wind direction. The predictions were made at 10 m height because the ambient air monitoring is carried at that height. The

stability class was assumed to be neutral (D), because usually near roadways, stability is neutral (Chock, 1977).

The eight hour averaging time concentration values are given in Tables 8.1.1 to 8.1.12 for each of the corridors and for different pollutants, under three wind speed conditions, at distances of 30 m and 305 m respectively from the centre of the road. The prediction were made for a receptor height of 10 m above the ground. It can be observed from the tables that the concentrations of TSP, SO_2 and NO_x are maximum on links 1, 2, 3, 8. This is because of large fleet of diesel driven goods vehicles on these links. CO and HC concentrations are high on links 1, 3, 2, 7, and 4 in the decreasing order of concentration levels. This is due to the large number of passenger vehicles in these corridors. It is important to note that lower wind speed produce high concentration levels and on some corridors the predicted levels exceed the standards. The predicted ambient concentration exceeds the standards for NO_x in corridor 1. HC levels is close to the US ambient standard (200 $\mu g/m_3$) in corridor 1. The high levels of pollution in some corridors is a cause of concern and need to be reduced out by various transportation planning methods.

Table 8.1.1. Average eight hourly concentrations across corridor 1 ($\mu g/m^3$)

Pollutant	ws1 = 0.7 m/s		ws2 = 2.1 m/s		ws3 = 4.2 m/s	
	30 m	305 m	30 m	305 m	30 m	305 m
TSP	1.2	4.3	0.8	2.9	0.6	2.1
SO_2	6.0	22.7	4.2	15.9	2.9	11
NO_x	40.0	150.2	28.1	105.3	19.4	72.6
HC	46.1	172.9	32.5	121.7	22.3	83.6
CO	163.9	615.0	114.9	431.0	79.3	297.4
Pb	0.06	0.24	0.05	0.17	0.03	0.12

Table 8.1.2. Average eight hourly concentrations across corridor 2 ($\mu g/m^3$)

Pollutant	ws1 = 0.7 m/s		ws = 2.1 m/s		ws = 4.2 m/s	
	30 m	305 m	30 m	305 m	30 m	305 m
TSP	0.3	1.1	0.2	0.8	0.2	0.6
SO_2	2.3	8.5	1.6	6.0	1.1	4.1
NO_x	14.4	53.9	10.1	37.7	6.9	26.0
HC	24.9	93.5	17.5	65.5	12.1	45.2
CO	90.0	337.3	63.0	236.3	43.5	163.1
Pb	0.04	0.14	0.03	0.1	0.02	0.07

Table 8.1.3. Average eight hourly concentrations across corridor 3 ($\mu g/m^3$)

Pollutant	ws = 0.7 m/s		ws = 2.1 m/s		ws = 4.2 m/s	
	30 m	305 m	30 m	305 m	30 m	305 m
TSP	0.7	2.6	0.5	1.8	0.3	1.2
SO_2	3.8	14.2	2.7	9.9	1.8	6.9
NO_x	26.4	99.2	18.5	69.5	12.8	48.0
HC	34.0	128.0	23.8	89.4	16.4	61.9
CO	120.9	254.0	85.0	318.0	58.5	219.3
Pb	0.05	0.16	0.03	0.13	0.02	0.09

Table 8.1.4. Average eight hourly concentrations across corridor 4 ($\mu g/m^3$)

Pollutant	ws = 0.7 m/s		ws = 2.1 m/s		ws = 4.2 m/s	
	30 m	305 m	30 m	305 m	30 m	305 m
TSP	0.2	0.9	0.2	0.6	0.1	0.4
SO_2	1.5	5.7	1.1	4.0	0.7	2.7
NO_x	7.6	28.3	5.3	19.9	3.7	13.7
HC	8.3	31.2	5.8	21.9	4.0	15.1
CO	29.5	110.5	20.6	77.5	14.3	53.5
Pb	0.01	0.04	NEG	0.03	NEG	0.02

Table 8.1.5. Average eight hourly concentrations across corridor 5 ($\mu g/m^3$)

Pollutant	ws = 0.7 m/s		ws = 2.1 m/s		ws = 4.2 m/s	
	30 m	305 m	30 m	305 m	30 m	305 m
TSP	0.5	1.7	0.3	1.2	0.2	0.8
SO_2	2.5	9.4	1.8	6.6	1.2	4.5
NO_x	15.9	59.5	11.1	41.7	7.7	28.8
HC	15.9	59.5	11.1	41.7	7.7	28.8
CO	55.2	207.0	38.6	145.0	26.7	100.1
Pb	0.02	0.06	0.01	0.06	0.01	0.04

Table 8.1.6. Average eight hourly concentrations across corridor 6 ($\mu g/m^3$)

Pollutant	ws = 0.7 m/s		ws = 2.1 m/s		ws = 4.2 m/s	
	30 m	305 m	30 m	305 m	30 m	305 m
TSP	0.2	0.9	0.2	0.6	0.1	0.4
SO_2	1.5	5.7	1.1	4.0	0.7	2.7
NO_x	9.1	34.0	6.4	23.8	4.4	16.5
HC	6.8	25.5	4.8	17.9	3.3	12.3
CO	22.7	85.0	15.9	59.6	11.0	41.1
Pb	NEG	0.03	NEG	0.02	NEG	0.02

Table 8.1.7. Average eight hourly concentrations across corridor 7 ($\mu g/m^3$)

Pollutant	ws = 0.7 m/s		ws = 2.1 m/s		ws = 4.2 m/s	
	30 m	305 m	30 m	305 m	30 m	305 m
TSP	0.4	1.4	0.3	1.0	0.2	0.7
SO_2	2.3	8.5	1.6	6.0	1.1	4.1
NO_x	12.8	48.2	9.0	33.8	6.2	23.3
HC	7.1	26.6	5.0	18.7	3.4	12.9
CO	23.4	87.9	16.4	61.6	11.3	42.5
Pb	NEG	0.03	NEG	0.02	NEG	0.01

Table 8.1.8. Average eight hourly concentrations across corridor 8 ($\mu g/m^3$)

Pollutant	ws = 0.7 m/s		ws = 2.1 m/s		ws = 4.2 m/s	
	30 m	305 m	30 m	305 m	30 m	305 m
TSP	0.4	1.4	0.3	1.0	0.2	0.7
SO_2	1.9	7.1	1.3	5.0	0.9	3.4
NO_x	12.1	45.4	8.5	31.8	5.8	21.9
HC	12.1	45.4	8.5	31.8	5.8	21.9
CO	41.6	155.9	29.1	109.2	20.1	75.4
Pb	0.01	0.06	0.01	0.04	NEG	0.03

Table 8.1.9. Average eight hourly concentrations across corridor 9 ($\mu g/m^3$)

Pollutant	ws = 0.7 m/s		ws = 2.1 m/s		ws = 4.2 m/s	
	30 m	305 m	30 m	305 m	30 m	305 m
TSP	0.2	0.9	0.2	0.6	0.1	0.4
SO_2	1.2	4.5	0.9	3.2	0.6	2.2
NO_x	7.6	28.3	5.3	19.9	3.7	13.7
HC	7.1	26.6	5.0	18.7	3.4	12.9
CO	24.9	93.5	17.5	65.5	12.1	45.2
Pb	NEG	0.04	NEG	0.03	NEG	0.02

Table 8.1.10. Average eight hourly concentrations across corridor 10 ($\mu g/m^3$)

Pollutant	ws = 0.7 m/s		ws = 2.1 m/s		ws = 4.2 m/s	
	30 m	305 m	30 m	305 m	30 m	305 m
TSP	0.01	0.05	0.0	0.04	0.0	0.02
SO_2	1.3	4.8	0.9	3.4	0.6	2.3
NO_x	9.1	34.0	6.4	23.8	4.4	16.5
HC	9.8	36.9	6.9	25.8	4.8	17.8
CO	34.8	130.4	24.4	91.4	16.8	63.1
Pb	0.2	0.9	0.2	0.6	0.1	0.4

Table 8.1.11. Average eight hourly concentrations across corridor 11 ($\mu g/m^3$)

Pollutant	ws = 0.7 m/s		ws = 2.1 m/s		ws = 4.2 m/s	
	30 m	305 m	30 m	305 m	30 m	305 m
TSP	0.08	0.28	0.05	0.2	0.04	0.14
SO_2	0.8	2.8	0.5	2	0.4	1.4
NO_x	3.0	11.3	2.1	7.9	1.5	5.5
HC	5.3	19.8	3.7	13.9	2.6	9.6
CO	20.4	76.5	14.3	53.6	9.9	37.0
Pb	0.0	0.03	0	0.02	0	0.02

Table 8.1.12. Average eight hourly concentrations across corridor 12 ($\mu g/m^3$)

Pollutants	ws = 0.7 m/s		ws = 2.1 m/s		ws = 4.2 m/s	
	30 m	305 m	30 m	305 m	30 m	305 m
TSP	0.04	1.4	0.3	1	0.2	0.7
SO_2	2.3	8.5	1.6	6.0	1.1	4.1
NO_x	11.3	42.5	7.9	29.8	5.5	20.1
HC	5.3	19.8	3.7	13.9	2.6	9.6
CO	15.9	59.5	11.1	41.7	7.7	28.8
Pb	0	0.02	0	0.01	0	0

8.2 Domestic, industry and intra-city transport emissions

The emissions from domestic (rural and urban), industry and intra-city transport for the city of Delhi are aggregated and apportioned to each of the grids. Tables 8.2.1 to 8.2.5 shows the source strength for each of the pollutant for the year 1991.

Table 8.2.1. Source strength from area source (industry, domestic and intra-city transport of Delhi (TSP)) (μg/m²-s)

Grid	1	2	3	4	5	6	7	8	9
A	0.000	0.000	0.005	0.292	0.000	0.000	0.000	0.000	0.000
B	0.000	0.002	0.001	0.004	0.001	0.037	0.019	0.000	0.000
C	0.062	0.005	0.005	0.234	0.011	0.070	0.001	0.000	0.000
D	0.000	0.002	0.563	1.128	0.822	0.012	0.016	0.001	0.000
E	0.000	0.001	0.001	0.009	0.091	0.183	0.004	0.004	0.006
F	0.000	0.009	0.001	0.001	0.073	0.045	0.001	0.002	0.001
G	0.000	0.001	0.001	0.001	0.001	0.000	0.000	0.000	0.000
H	0.000	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000
I	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

* Intra-city emissions from transport sector of Delhi

Table 8.2.2. Source strength rate from area source (industry, domestic and intra-city transport of Delhi (CO)) (μg/m²-s)

Grid	1	2	3	4	5	6	7	8	9
A	0.000	0.001	0.030	1.269	0.000	0.000	0.001	0.000	0.000
B	0.001	0.014	0.005	0.023	0.008	0.095	0.030	0.002	0.000
C	0.240	0.033	0.031	0.994	0.035	0.262	0.008	0.003	0.000
D	0.003	0.014	0.154	0.939 6.9*	1.097 3.3*	0.053	0.021	0.006	0.000
E	0.003	0.005	0.005	0.042	0.347	0.094	0.025	0.026	0.008
F	0.002	0.018	0.006	0.005	0.034	0.005	0.014	0.013	0.004
G	0.002	0.003	0.003	0.004	0.004	0.000	0.000	0.000	0.000
H	0.000	0.054	0.002	0.000	0.000	0.000	0.000	0.000	0.000
I	0.000	0.000	0.002	0.001	0.000	0.000	0.000	0.000	0.000

* Intra-city emissions from transport sector of Delhi

Table 8.2.3. Source strength from area source (industry, domestic and intra-city transport of Delhi (SO_2)) ($\mu g/m^2$-s)

Grid	1	2	3	4	5	6	7	8	9
A	0.000	0.000	0.001	0.274	0.000	0.000	0.000	0.000	0.000
B	0.000	0.000	0.000	0.000	0.000	0.016	0.002	0.000	0.000
C	0.062	0.000	0.000	0.290	0.003	0.027	0.000	0.000	0.000
D	0.000	0.000	0.072	0.034 0.13*	0.512	0.004	0.002	0.000	0.000
E	0.000	0.000	0.000	0.006	0.075	0.016	0.000	0.000	0.002
F	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000
G	0.000	0.000	0.000	0.000	0.002	0.002	0.000	0.000	0.000
H	0.000	0.007	0.000	0.000	0.000	0.000	0.000	0.000	0.000
I	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

* Intra-city emissions from transport sector of Delhi

Table 8.2.4. Source strength from area source (industry, domestic and intra-city transport of Delhi NO_x)) ($\mu g/m^2$-s)

Grid	1	2	3	4	5	6	7	8	9
A	0.000	0.000	0.000	0.145	0.000	0.000	0.000	0.000	0.000
B	0.000	0.000	0.000	0.000	0.000	0.004	0.038	0.000	0.000
C	0.043	0.000	0.000	0.216	0.002	0.008	0.000	0.000	0.000
D	0.000	0.000	0.026	0.007 0.6*	0.123 0.3*	0.028	0.002	0.000	0.000
E	0.000	0.000	0.000	0.004	0.056	0.021	0.000	0.000	0.001
F	0.000	0.001	0.001	0.008	0.006	0.000	0.000	0.000	0.000
G	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
H	0.000	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000
I	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

* Intra-city emissions from transport sector of Delhi

Table 8.2.5. Source strength from area source (industry, domestic and intra-city transport to Delhi (HC)) ($\mu g/m^2$-s)

Grid	1	2	3	4	5	6	7	8	9
A	0.000	0.000	0.000	0.290	0.000	0.000	0.000	0.000	0.000
B	0.000	0.000	0.000	0.000	0.000	0.021	0.003	0.000	0.000
C	0.065	0.000	0.000	0.261	0.002	0.010	0.000	0.000	0.000
D	0.000	0.000	0.039	0.003 2.9*	0.175 1.4*	0.003	0.001	0.000	0.000
E	0.000	0.000	0.000	0.006	0.076	0.016	0.000	0.000	0.002
F	0.000	0.001	0.001	0.000	0.010	0.000	0.002	0.000	0.000
G	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
H	0.000	0.007	0.000	0.000	0.000	0.000	0.000	0.000	0.000
I	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

* Intra-city emissions from transport sector of Delhi

In order to translate the source strengths into surface concentrations, area source model was used. This model can be applied satisfactorily because the source emissions are spread out uniformly throughout the grid and the emissions are at a low level. In the present study, simple and realistic, source oriented Atmospheric Turbulence and Diffusion Laboratory (ATDL) model was used to estimate the long-term concentration of pollutants. The model can be applied satisfactorily for regions where emissions are at low level- such as the emissions from domestic, commercial and transport and low level industrial pockets - and are uniformly distributed. Work has already been done on application of ATDL model to Bombay city with satisfactory results (Munshi U, Patil R.S 1979).

The salient features of the model are:

1. Algorithm is based on ATDL model assumptions.
2. Model predicts average surface concentration.
3. Model considers impact of upwind grids on the receptor grid.

Since the model is used for long term concentration predictions, neutral stability conditions were considered. The model was run for three wind speeds viz 0.7 m/s, 2.1 m/s and 4.2 m/s. Assumption is made that wind blows in only one direction. The source strength of the grid upwind of the receptor grid is not considered because of the large grid size. Tables 8.2.6 to 8.2.10 show the concentrations for each of the grids for different pollutants. Five high polluting grids were identified. Table 8.2.11

shows five high polluting grids in the decreasing order of importance for each of the pollutant (TSP, CO, SO_y, NO_x, HC). It can be observed that the concentration levels of decreases with increasing wind speeds. The concentration levels of TSP exceeds the permissible standards (annual average) for grids D3, D4 and D5 for low wind speed conditions. The concentration of CO is close to permissible standard in grid D4. SO_2 exceeds the standards in grid D4, D5, C4, and A4 whereas NO_x exceeds in D4, D5 and C4 respectively. D4 and D5 have high levels owing to intra-city transport emission levels, whereas C4 and A4 have high industrial emissions. It can be concluded that grids D4, D5, C4 and A4 have very high levels of pollution and can be considered as sensitive.

Table 8.2.6. Grid-wise concentration: TSP

	Grid	1	2	3	4	5	6	7	8	9
WS1	A			2.7	179.2					
WS2				0.9	60.0					
WS3				0.45	30.0					
WS1	B						23.9	12		
WS2							8.0	4		
WS3							4.0	2		
WS1	C	35.9			137.4	6.0	41	6		
WS2		11.9			45.8	2	14	2		
WS3		6.0			22.9	1	7	1		
WS1	D			334.4	675	490	6	11.9		
WS2				111.5	225	163.2	2	4.2		
WS3				55.7	112.5	81.6	1			
WS1	E				5.4	54	107.5			
WS2					1.8	18	35.8			
WS3					0.9	9	17.9			
WS1	F		5.4			41.8	23.9			
WS2			1.8			13.9	8			
WS3			0.9			7	4			
WS1	G					0.4				
WS2						0.1				
WS3						.07				
WS1	H		6							
WS2			2							
WS3			1							
WS1	I									
WS2										
WS3										

Table 8.2.7. Grid-wise concentration: CO

	Grid	1	2	3	4	5	6	7	8	9
WS1	A			17.9	776.4					
WS2				6	258.8					
WS3				3	129.4					
WS1	B		6		11.9		53.7	17.9		
WS2			2		4		17.9	6		
WS3			1		2		9	3		
WS1	C	143.3	17.9	17.9	579.2	17.9	179.2			
WS2		47.8	6	6	199.1	6	59.7			
WS3		23.9	3	3	99.5	3	29.9			
WS1	D		6	119.4	4658	2627.7	29.9	11.9		
WS2			2	39.8	1552.7	875.9	10	4		
WS3			1	19.9	776.4	437.9	5	2		
WS1	E				23.9	209	53.7	17.9	17.9	
WS2					8	69.7	17.9	6	6	
WS3					4	34.8	9	3	3	
WS1	F		11.9			17.9		6	6	
WS2			4			6		2	2	
WS3			2			3		1	1	
WS1	G									
WS2										
WS3										
WS1	H		29.9							
WS2			10							
WS3			5							
WS1	I									
WS2										
WS3										

Table 8.2.8. Grid-wise concentration: NO_x

	Grid	1	2	3	4	5	6	7	8	9
WS1	A				71.7					
WS2					23.9					
WS3					11.9					
WS1	B							23.9		
WS2								8		
WS3								4		
WS1	C	23.9			131.4					
WS2		8			43.8					
WS3		4			21.9					
WS1	D				358.3	250.8	17.9			
WS2					119.4	83.6	6			
WS3					59.7	41.8	3			
WS1	E					35.8	11.9			
WS2						11.9	4			
WS3						6	2			
WS1	F									
WS2										
WS3										
WS1	G									
WS2										
WS3										
WS1	H									
WS2										
WS3										
WS1	I									
WS2										
WS3										

Table 8.2.9. Grid-wise concentration: SO_2

	Grid	1	2	3	4	5	6	7	8	9
WS1	A				179.2					
WS2					59.7					
WS3					29.9					
WS1	B						11.9			
WS2							4.0			
WS3							2			
WS1	C	35.8			179.2		6			
WS2		11.9			59.7		2			
WS3		6 8 4			29.9		1			
WS1	D				1731.9	836.1				
WS2					577.3	278.7				
WS3					288.7	139.3				
WS1	E					47.8	11.9			
WS2						15.9	4			
WS3						8.0	2			
WS1	F									
WS2										
WS3										
WS1	G									
WS2										
WS3										
WS1	H									
WS2										
WS3										
WS1	I									
WS2										
WS3										

Table 8.2.11. Order of importance

Pollutant	1	2	3	4	5
TSP	D4	D5	D3	A4	C4
CO	D4	D5	A4	C4	E5
SO_2	D5	C4	A4	D4	E5
NO_x	D4	D5	C4	A4	E5
HC	D4	D5	A4	C4	E5

Table 8.2.12. Location of Grids

Grid	
A4	Panipat
C4	Baghpat, parts of Sonipat and Delhi
D3	Bahadurgarh and parts of Delhi
D4	Delhi
D5	Part of Delhi, Ghaziabad and Loni
E5	Faridabad

8.3 Concentration from power plants

Power generation is one of the major source of pollution in the NCR. The ambient ground level concentrations of pollutants not only depends on the rate of emission and the stack height, but also on the meteorological features such as wind speed, stability conditions, etc. Also the efficiency of dispersion or the avoidance of plume droop depends not only on the height of the stack but also on the temperature and velocity at which the flue gas is released into the atmosphere.

To predict the ground level concentrations, it is necessary to simulate the atmospheric dispersion of pollutants under a range of possible atmospheric conditions using air quality model. TERI has developed a computer simulation Gaussian Plume Dispersion Model (GPM). The salient features of the model are:

1. Algorithms are based on Gaussian plume modelling assumptions.
2. Model predicts ground level concentration (GLCs), maximum GLC, distance at which maximum GLC occurs and distance at which plume touches the ground.
3. Model predicts short-term (eight-hour averaging time) and long-term (seasonal or annual) concentrations.

4. Model predicts concentrations under worst atmospheric conditions (fumigation and trapping).

Power plants are considered as point sources. Since atmospheric conditions vary, the objective here is to calculate the spatial and temporal variations in pollutant concentrations under various conditions. For this study a spatial scale of 30 km was used and the time scale of eight-hour averaging time, were used.

Table 8.2.13 shows various power plants in the National Capital Region. The technical data like the exit velocity, flue gas temperature, flue gas quantity are assumed to be for a typical power plant. A study carried out by TERI (TERI, 1991) forms the basis for these figures. Since the height of the stack for each of the power plants was not available, minimum stack height described by the Central Pollution Control Board was used. Table 8.2.14 shows the minimum stack height standards.

Table 8.2.13. Power plants in NCR

		Capacity	Stack height	Diameter	Temperature	Exit velocity	Flue gas quantity	Pollutant Emission (g/s)				
		(MW)	(m)	(m)	(°C)	(m/s)	(g/s)	TSP	SO_2	CO	HC	NO_x
1	Panipat	440	130.2	5.8	140	20	621651	24.1	469.9	61.8	30.9	463.7
2	Delhi (IP and Rajghat)	299	116	5.8	140	20	432408	16.4	319.4	42.1	21.0	315.2
3	Badarpur	720	220	5.8	140	20	1041030	39.5	768.9	101.2	54.4	758.9
4	Faridabad	195	102	5.8	140	20	281984	10.7	208.3	27.4	13.7	205.4
5	Dadri	210	220	5.8	140	20	303666	11.5	147.0	29.5	14.7	221.3

Table 8.2.14. Minimum stack height standards

Boiler size (MW)	Stack height (m)
>500	275
200-500	220
<200	$14Q^{0.3}$*

*Q: Sulphur dioxide emission rate (in kg/hr)

Source: Mathur Ajay, 1989

To cover the entire range of wind speeds and stability, the model was initially run for unstable, neutral and stable atmospheric conditions for three wind speeds that

ranged from low (0.7 m/s), average (2.1 m/s) to high (4.2 m/s). It was observed that stable conditions lead to very high plume rise and consequently very low GLCs in the range of 10 km and beyond. However, neutral and unstable condition give rise to moderate to higher levels of GLCs.

Tables 8.2.15 to 8.2.18 show GLCs for three wind speeds under neutral and unstable conditions for each of the power plant and pollutant. It is evident that the cause of concern is the high levels of SO_2 and NO_x (at all the plants), which are uncontrolled and have high emission rates vis-a-vis other pollutants. Figure 8.3.1 to 8.3.20 shows GLCs for three wind speeds under unstable conditions for SO_2 and NO_x.

It is observed that power plants in Panipat followed by Delhi and Faridabad contribute maximum high concentration level ranging from 35-55 $\mu g/m_3$ under unstable conditions.Maximum GLCs occur at a distance of 2-4 km from the stack. Though the source strength of Badarpur plant is very high, vis-a-vis panipat, Delhi, Faridabad, the GLCs are observed to be less than these plants because of higher stack height. Higher wind speeds produced higher GLCs nearer to the plants. However at distances greater than 6 km higher wind speeds produced lower concentration. This is because, wind speeds affect GLCs in two ways. Higher wind speed produce lower plume rise which in turn increase GLCs near the plant. However, higher wind speeds also give dispersion and therefore, at farther distances there is a reduction in GLCs. The concentrations beyond 10 km is insignificant.

The worst atmospheric conditions are associated with the phenomenon of trapping and fumigation. The convective conditions that correspond to unstable atmosphere are normally associated with a mixing layer of finite height that is frequently capped by an elevated inversion. The inversion layer serves as an impenetrable barrier confining the pollutants below. This phenomenon generally occurs in winter. A mixing depth of 250 m which was observed during the winter season in Delhi was assumed for all the sub-regions. Average wind speed was assumed. Fumigation occurs when there is a breakup of the inversion layer. It usually occurs at mid-morning The thermal eddies that are generated due to this phenomena result in very high concentration levels. Fumigation condition produce very high GLCs with concentrations reaching a maximum of 79 $\mu g/m^3$ at a distance less than 1 km for Panipat power plant. The trend is the same across different power plants. Under trapping conditions, concentrations reach a maximum of 35 $\mu g/m_3$ at a distance of 3-4 km. As the concentration beyond 10 km is insignificant, grids in which the power plant is located will encounter high pollution levels. Thus, grids A4, D4, D5, E5, and D6 will experience high levels of pollution in the decreasing order of significance.

Table 8.2.15. Impact of Panipat power plant (µg/m³)

Model	TSP		SO_2		CO		HC		NO_x	
Condition	D	Max GLC	D	Max GLC	D	Max GLC	D	Max GLC	D	Max GLC
WS1										
Neutral			35	11					36	11
Unstable			10.6	14.8	10.6	2			10.6	15
WS2										
Neutral			11.4	28	11.4	3.7			11.4	28
Unstable			3.6	37	3.6	5	3.6	2	3.6	36
Fumigation	< 1	4.1	< 1	79.5	< 1	10.4	< 1	5.3	< 1	78.4
Trapping	3-4	1.85	3-4	36	3-4	5	3-4	2	3-4	36
WS3										
Neutral	6.5	2	6.5	38	6.5	5			6.5	38
Unstable	2.1	2.6	2.1	51	2	7	2.1	3.4	2.1	50

Table 8.2.16. Impact of Faridabad power plant (µg/m³)

Model	TSP		SO_2		CO		HC		NO_x	
Condition	D	Max GLC	D	Max GLC	D	Max GLC	D	Max GLC	D	Max GLC
WS1										
Neutral			26	8.8					26	8.6
Unstable			7.8	11.6					7.8	11.5
WS2										
Neutral			8.3	21.7					8.3	21.3
Unstable			2.7	28.6	2.7	3.8			2.7	28.1
Fumigation	< 1	2.8	< 1	54.5	< 1	7.2	< 1	3.6	< 1	53.8
Trapping			2-3	28	2-3	3.7			2-3	28
WS3										
Neutral			4.7	29					4.7	29
Unstable	1.5	2.1	1.5	39.9	1.5	5.3			1.5	39.3

Table 8.2.17. Impact of Delhi power plant ($\mu g/m^3$)

Model Condition	TSP		SO_2		CO		HC		NO_x	
	D	Max GLC	D	Max GLC	D	Max GLC	D	Max GLC	D	Max GLC
WS1										
Neutral			30.7	10					31	9.9
Unstable			9.2	13					9.2	13
WS2										
Neutral			9.8	25					9.8	24.5
Unstable			3	32.5	3.2	4.3	3.2	2.1	3.2	32
Fumigation	< 1	3.1	< 1	60.7	< 1	79.9	< 1	4	< 1	59.9
Trapping	3-4	1.7	3-4	32	3-4	4.3	3-4	2.1	3-4	31.9
WS3										
Neutral			5.6	34					5.6	33.2
Unstable	1.8	2.3	1.8	46	1.8	6	1.8	3	1.8	44.9

Table 8.2.18. Impact of Badarpur power plant ($\mu g/m^3$)

Model Condition	TSP		SO_2		CO		HC		NO_x	
	D	Max GLC	D	Max GLC	D	Max GLC	D	Max GLC	D	Max GLC
WS1										
Neutral			53	9					53	9
Unstable			16	11.4					16	11.2
WS2										
Neutral			18	20					18	20
Unstable			5.7	26	5.7	3.4			5.7	26
Fumigation	< 1	3.4	< 1	66	< 1	8.7	< 1	4.6	< 1	65.
Trapping			5-6	26	5-6	3.4	5-6	1.8	5-6	25.7
WS3										
Neutral			11	25					10.8	25
Unstable			3.4	35	3.4	4.5	3.4	2.4	3.4	34

Fig 8.3.1 Panipat power plant : SO2 (down wind and unstable condition)

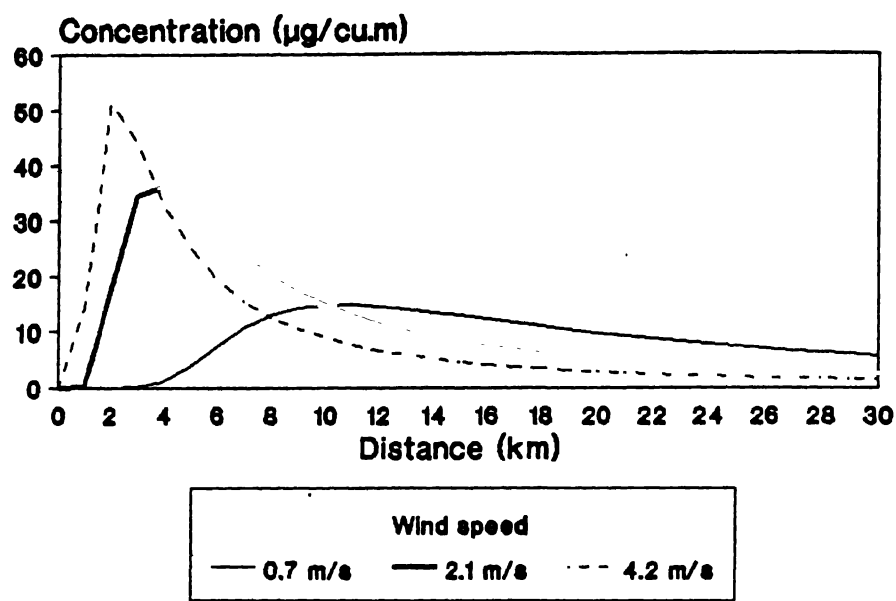



Fig 8.3.2 Panipat power plant - SO2 (fumigation and trapping conditions)

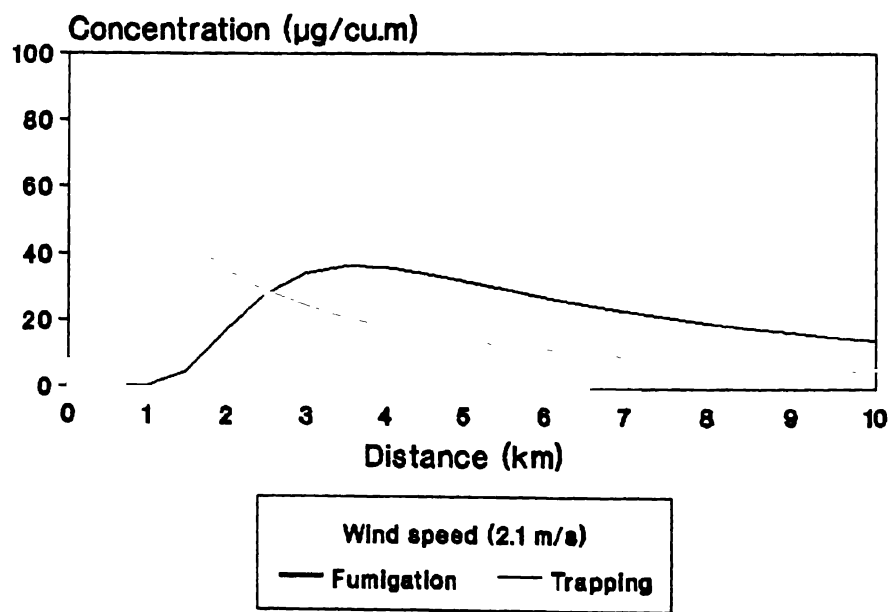



Fig 8.3.3 Delhi power plant - SO2
(down and unstable conditons)

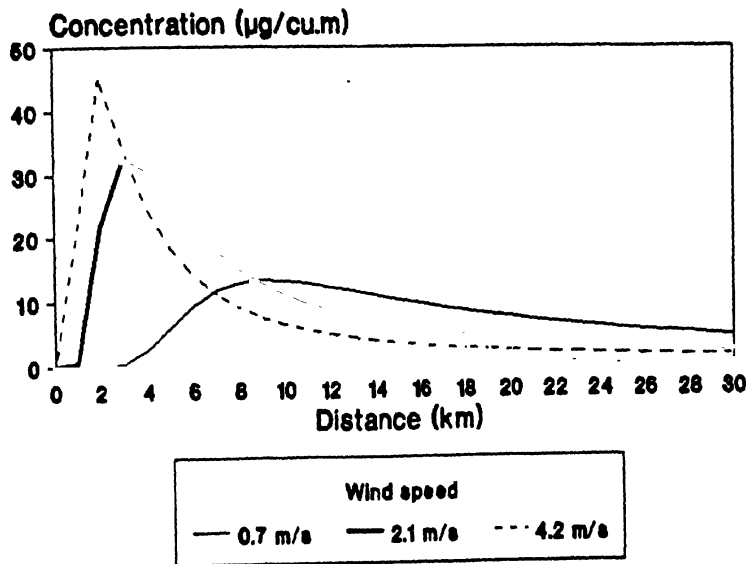



Fig 8.3.4 Delhi power plant - SO2
(fumigation and trapping conditions)

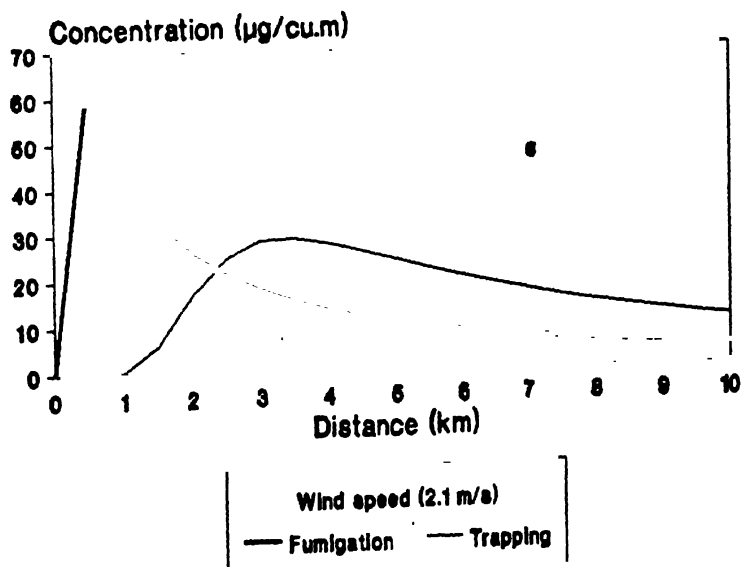



Fig 8.3.5 Faridabad power plant : SO2 (down wind and unstable conditions)

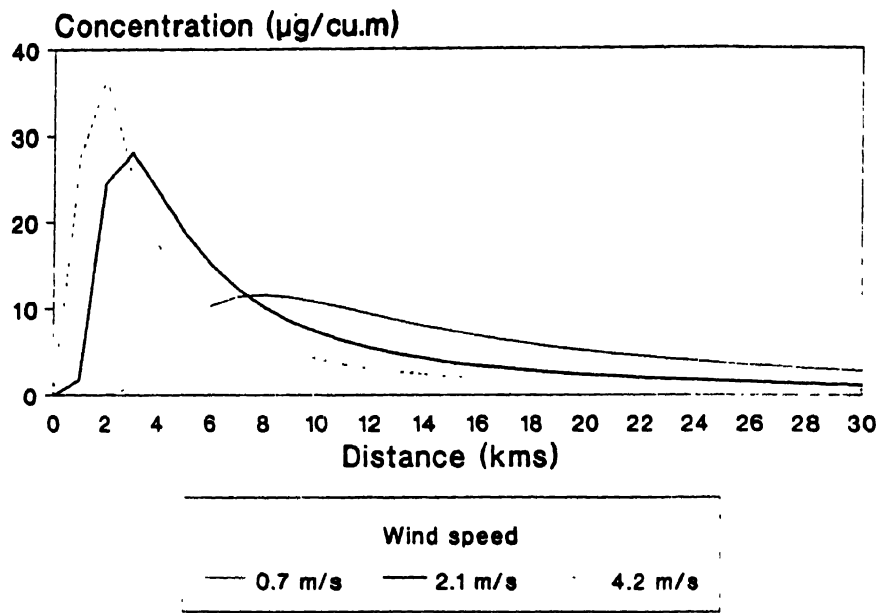



Fig 8.3.6 Faridabad power plant - SO2 (fumigation and trapping conditions)

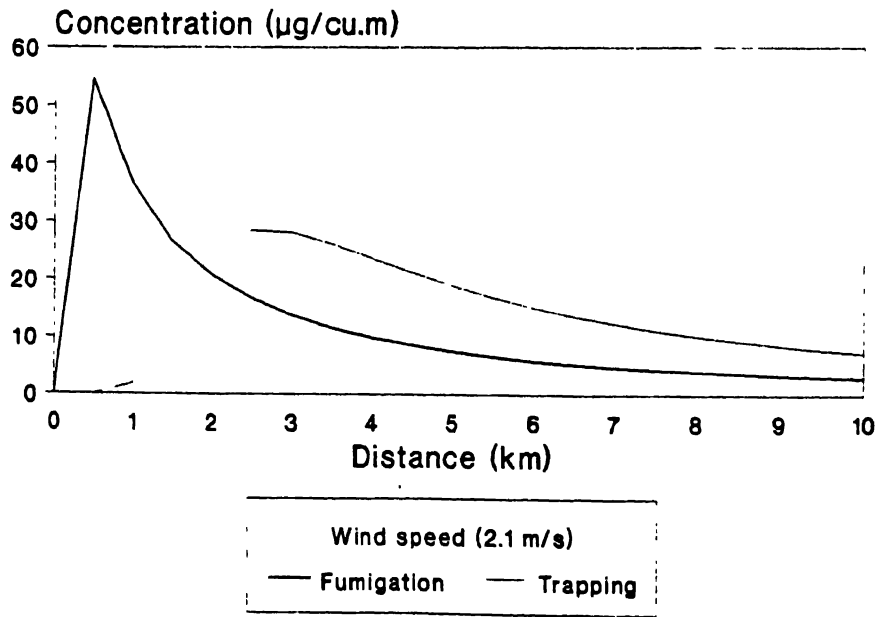



Fig 8.3.7 Badarpur power plant - SO2 (down wind and unstable conditions)

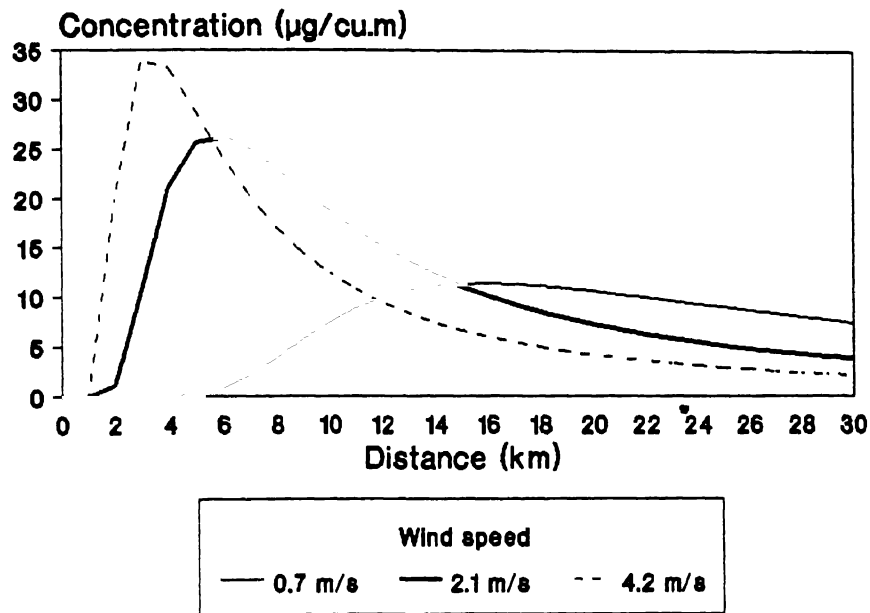



Fig 8.3.8 Badarpur power plant - SO2 (fumigation and trapping conditions)

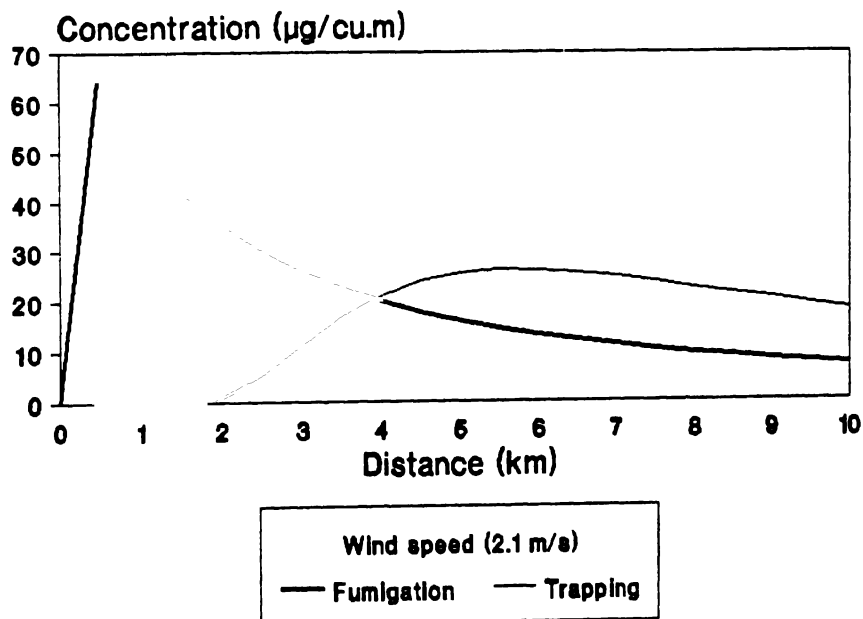



Fig 8.3.9 Dadri power plant - SO_2
(down wind and unstable conditions)

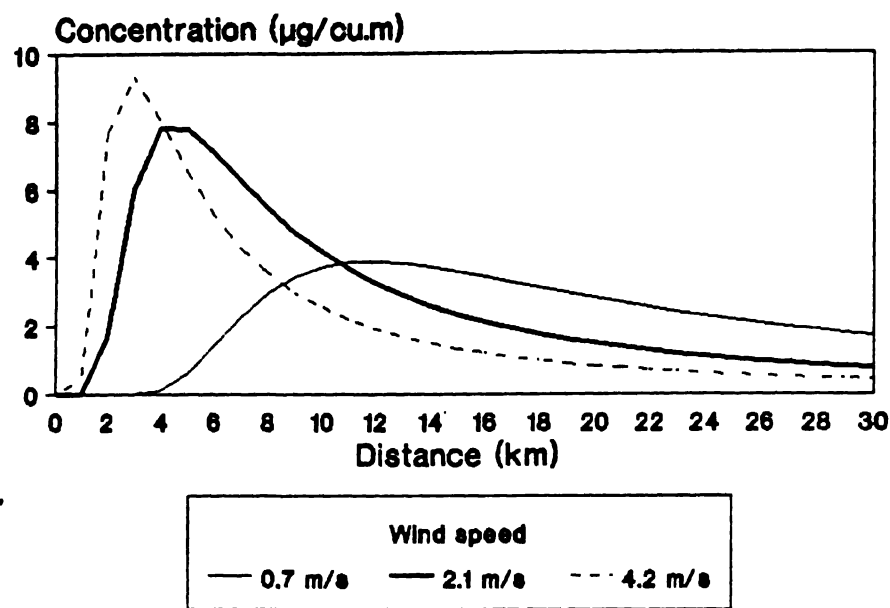



Fig 8.3.10 Dadri power plant - SO_2
(fumigation and trapping conditions)

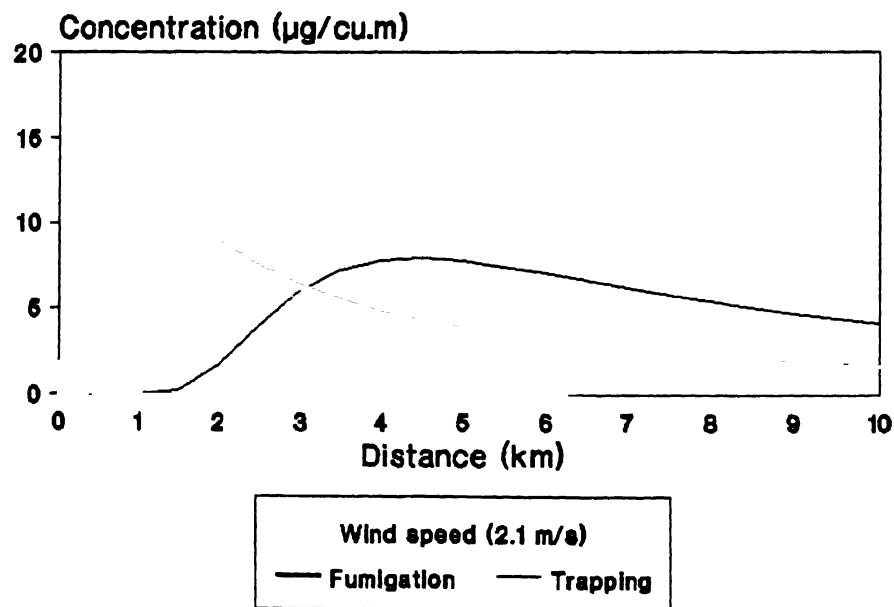



Fig 8.3.11 Panipat power plant - NOx
(down wind and unstable conditions)

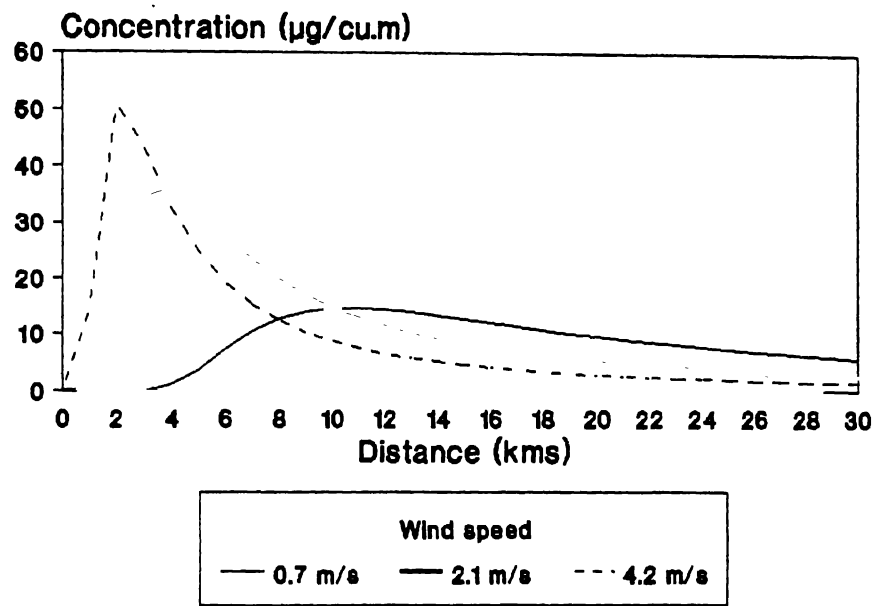



Fig 8.3.12 Panipat power plant - NOx
(fumigation and trapping conditions)

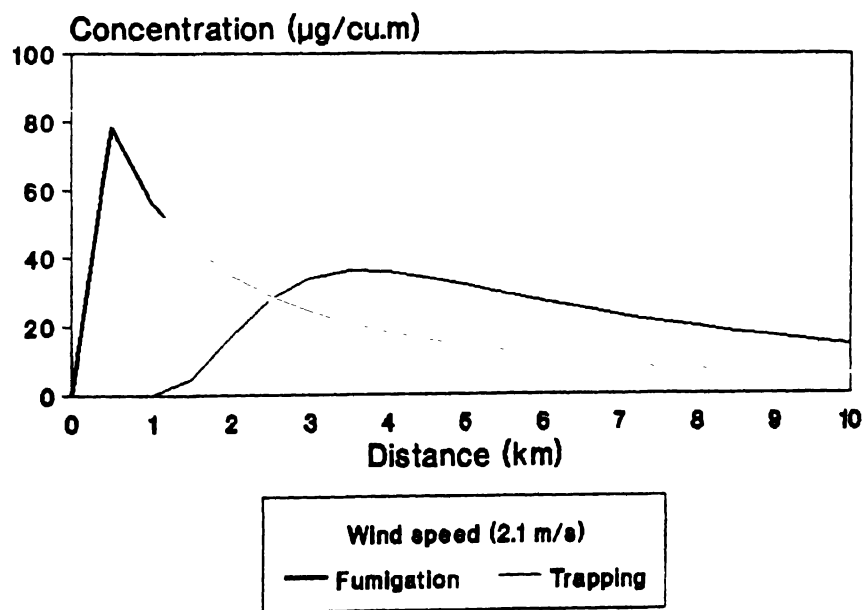



Fig 8.3.13 Delhi power plant - NOx (down wind and unstable conditions)

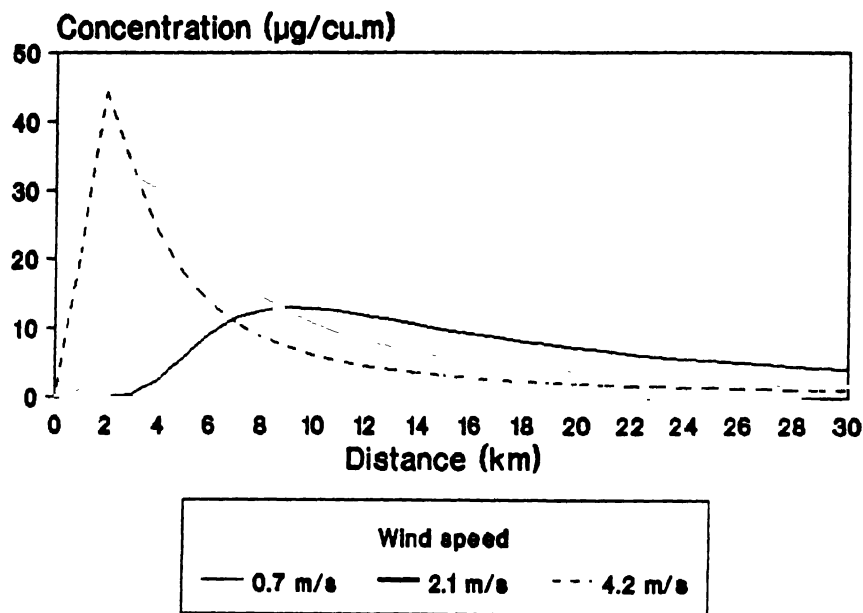



Fig 8.3.14 Delhi power plant - NOx (fumigation and trapping conditions)

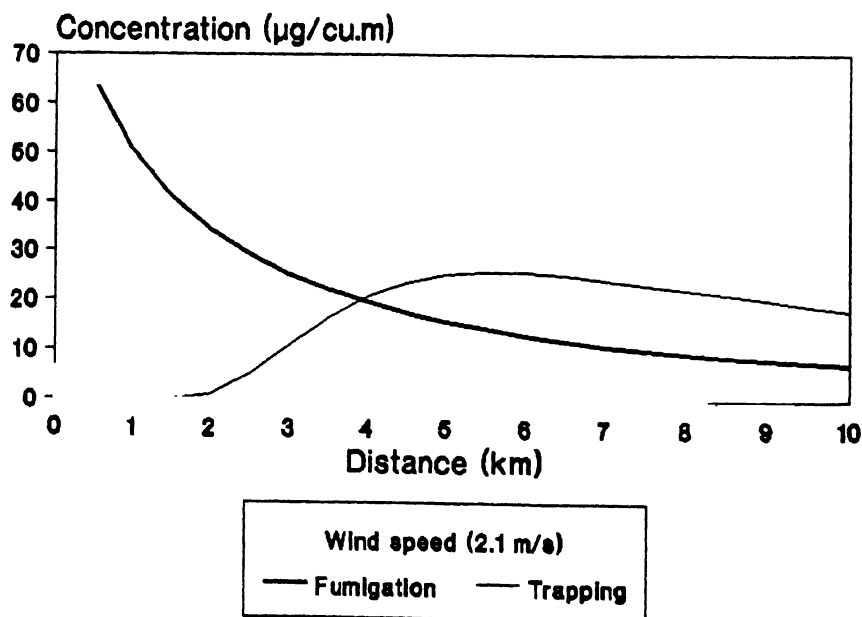



Fig 8.3.15 Faridabad power plant - NOx
(down wind and unstable conditions)

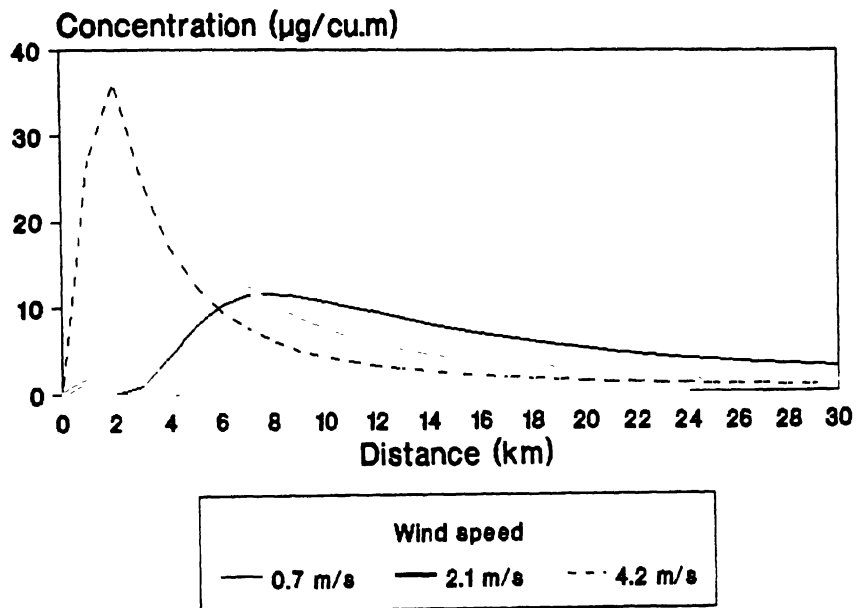



Fig 8.3.16 Faridabad power plant - NOx
(fumigation and trapping conditions)

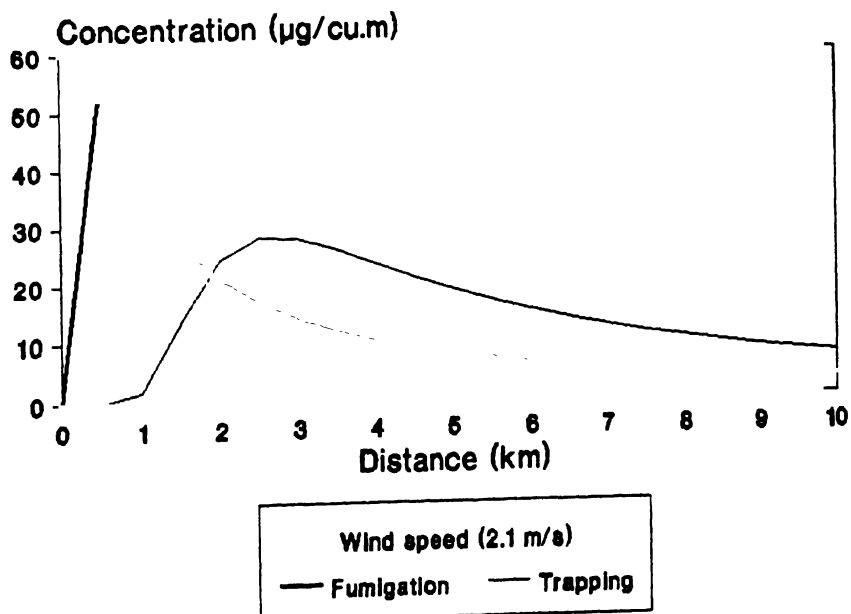



Fig 8.3.17 Badarpur power plant - NOx (down wind and unstable conditions)

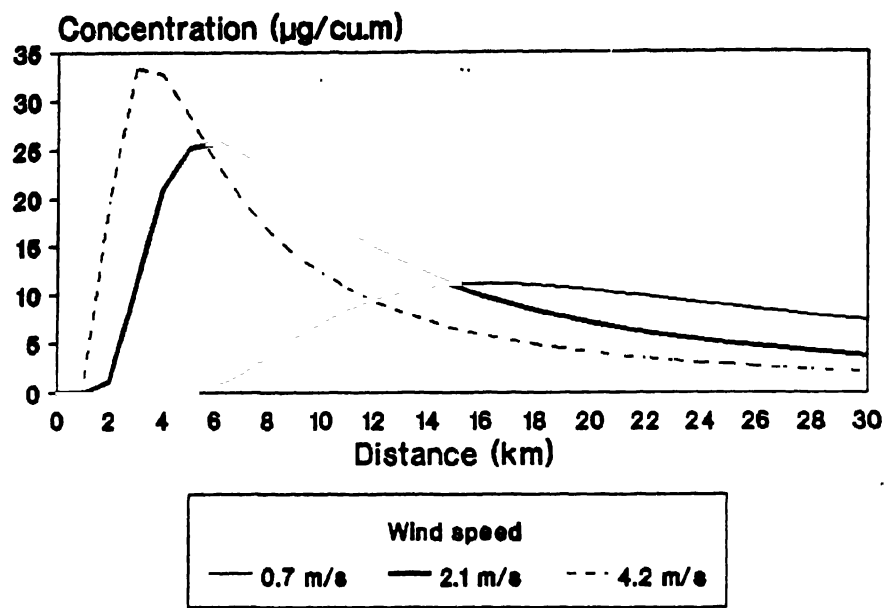



Fig 8.3.18 Badarpur power plant - NOx (fumigation and trapping conditions)

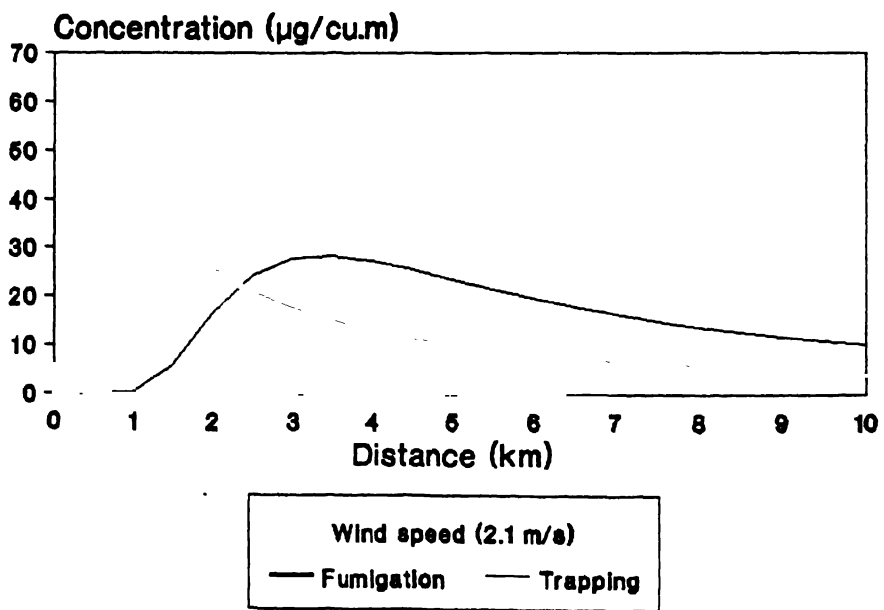



Fig 8.3.19 Dadri power plant - NOx
(down wind and unstable conditions)

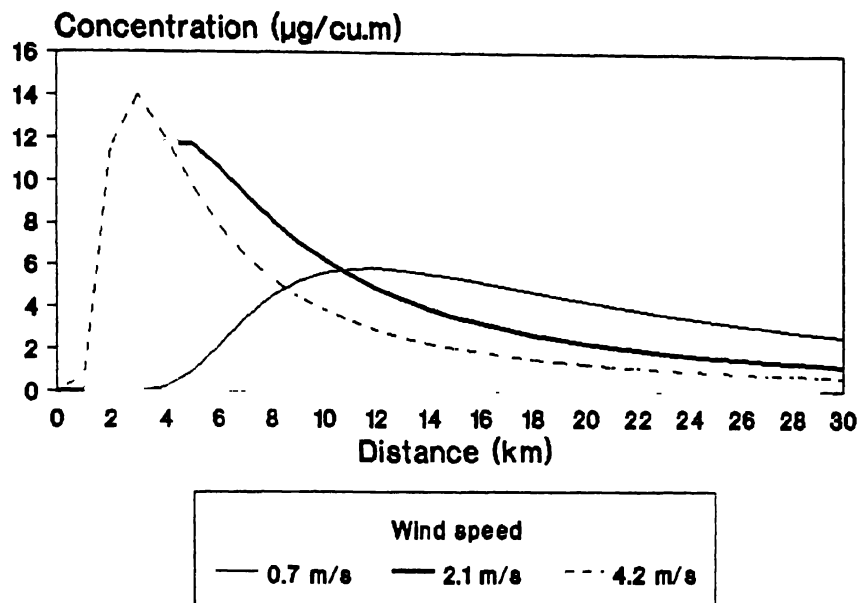
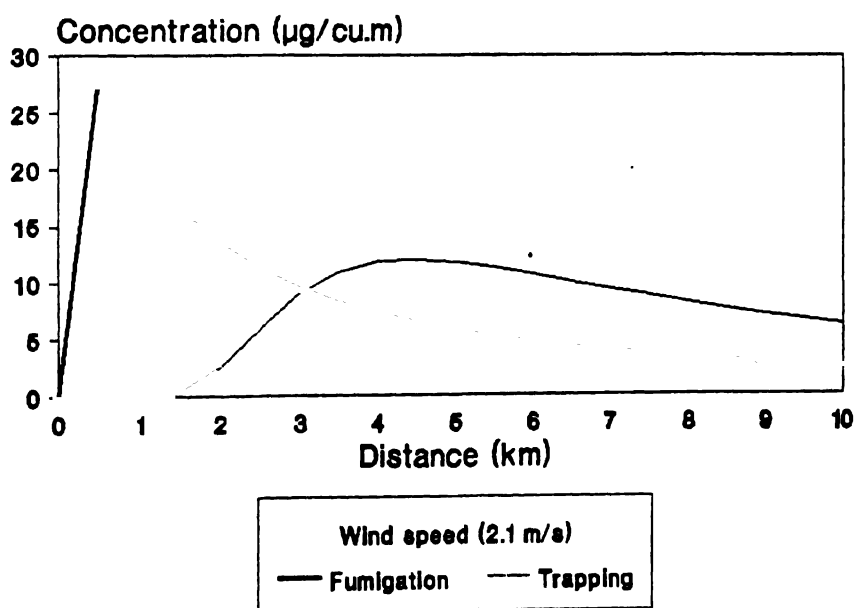



Fig 8.3.20 Dadri power plant - NOx
(fumigation and trapping conditions)

Chapter 9

Recommendations

The emission factor is an important independent variable in assessing the pollution loading. The available emission factors are outdated and in some cases, are borrowed from developed countries. But the applicability of data is limited because of the differences in the technological levels of industries in India and the developed nations. A study carried out by the Indian Institute of Petroleum,in 1983, for measuring the emission factors was not updated, even though state-of-the-art technology has entered the market. There is an urgent need for generating data on emission factors for different end-uses. The emission factors strongly depend on speed and age of the vehicles. Surveys need to be conducted to examine the effect of speed and age, and other factors, to arrive at a realistic picture of the state of the environment.

Transportation sector

Emissions from vehicular movement in corridors, other than the major corridors considered in this study were not available. In some cases, the data exists, but is incompatible with the framework of this study. Traffic surveys are necessary to assess the vehicle density in several of the minor corridors, and for updating the available figures for the major corridors.

In the present study intra-city emissions were estimated for the city of Delhi only. Data need to be generated for other growing urban centres such as Bulandshahr, Ghaziabad, Hapur, Meerut, Faridabad, Gurgaon, Panipat, Rohtak, Sonipat and Alwar. The spatial distribution of movement of vehicles within a city can help in the analysis of air quality. This exercise can be done through an O-D survey.

Goods vehicles contribute a substantial amount of NO_x, SO_2 and TSP.The data on goods vehicular movement for intra-city operation are totally lacking for any of the city. It is imperative to study the travel characteristics of goods vehicles.

Assumptions are made with regard to the fuel efficiency and utilization of vehicles. Primary surveys need to carried out to strengthen the database, so that the city specific parameters, which depend on the size of the city, living standards and the mobility pattern of commuters, can be examined in detail.

Industry

The data on air polluting industries has limitations - (i) the listing of air polluting industries is not exhaustive, especially in the Rajasthan sub-region, (ii) the data for industries in different regions are for different years, and (iii) the location of many of the previously surveyed industries was not available. A detailed survey of industries has to be conducted to map the exact location of industries, amount of fuel consumed and control technologies adopted, if any. The grid size can be reduced by generating this data.

Domestic sector

The data on domestic fuel consumption in both urban and rural sectors are grossly lacking. A study carried out by NCAER in 1975 is the only comprehensive document available. The study presents the variations in the consumption patterns across regions and across different class of urban and rural settlements. Primary surveys, to establish the fuel consumption pattern and mix in both urban (of different classes) and rural settlements of NCR will be required.

Power plants

Assumptions were made about the temperature of flue gases, emission rate of flue gas, excess air, diameter of the stack and the stack height, etc. To arrive at the actual conditions data will have to be generated.

Meteorology and air quality

Meteorology is an important factor influencing pollution. The data on meteorology are grossly inadequate. There is only one primary meteorological station in the city of Delhi. A network of stations in collaboration with IMD stations needs to be established to study the seasonal and diurnal variations. To begin with, the meteorological stations can be located in sensitive grids identified in the present study.

Inversion condition, an important phenomenon that increases the ambient concentration levels is a common occurrence in the north India. There is one observatory to measure the height of inversion. Studies to measure stability and inversion phenomena have to be carried out.

At present only NO_x, SO_2 and TSP are being measured at Delhi and Faridabad only. Air quality data need to be generated at several places especially in urban areas, across high density corridors and in sensitive grids. The data will help to validate the models used and to develop sophisticated modelling techniques. Measurement of pollutants such as CO and HC also needs to be undertaken, at least in the sensitive zones.

Source code

Point source model

```
c    a, b, c, d : constants used in asme model for dispersion
c               coefficient estimation
c    p :        wind profile exponents for different stability
c               classes
c    cp :       specific heat capacity in cal/g-k
c    ta :       ambient temperature in °k
c    ts :       efflux temperature in °k
c    qm :       emission rate in gm/sec
c    sd :       stack diameter at exit in m
c    vexit :    exit flue gas velocity in m/s
c    qn :       emission rate of nox in g/s
c    hstack :   height of stack in m
c    vstack :   wind velocity at stack height in m/s
c    hground :  height at which concentrations are calculated
c    vground :  wind velocity at ground level (at 10 m height)
c    deltah :   plume rise in m.
C    heff :     effective height of stack in m.
c    veff :     wind velocity at effective height of stack in m/s
c    aa :       wind stability category
c    ab :       dispersion stability category
c    xb, xe, xinc : location begin,end,increment in x direction
c    yb,ye,yinc   : location begin,end,increment in y direction
c    z :        location in z direction
c    cf,ct :    labels for fumigation and trapping 'ys'or'no'
c    sl :       height of mixing layer in m
c    sc :       label for seasonal concentration 'ys' or 'no'
c    fds (i,j) : frequency of wind in I th wind speed class and
c               in the j th direction
c    sigmay :   dispersion coeff. In the y direction in mts.
c    sigmaz :   dispersion coeff. In the z direction in mts.
c    conc and cone : concentrations one hour & eight hour averaging
c                  time in micro gms/mt^3
c    xg & xmax : distance at which the plume touches the ground
c               and where concentration is maximum  mts
c  glcmax , gcmaxe : max ground level concentration 1 hr & 8 hr avg
c  hf :          effective plume rise under fumigation condition
c  sigyf :       dispersion coefficient under fumigation
c  concf & confe : concentration under fumigation 1 hr & 8 hr
```

```
c   conct : conte : concentration under trapping 1 hr & 8 hr
c   vav :          wind class avg  velocity (km/hr)
c   ld :           wind directions  1,..,8
c   ls :           wind classes  1,...,4
c   sconc &scone :  seasonal concentrations 1 hr and 8 hr averages
c
c
      dimension p(6), a(4), b(4), c(4), d(4), conc(100), x(100),
     +          sigmay(100), sigmaz(100), hf(100), sigyf(100),
     +          concf(100), conct(100), sum(100), vav(4), hs(4),
     +          sconc(8,100), fds(4,8), cone(100), confe(100),
     +          conte(100), scone(8,100)
      real  parta, partb, partc, sigmay, sigmaz, conc
      integer xb, xe, xinc, yb, ye, yinc, z
      character aa*1, ab*1, cf*2,ct*2,sc*2, az*15, ay*30, se*15
      open(1, file='arr.Dat', status='old')
      data a, b, c, d, p / 0.40, 0.36, 0.32, 0.31,
     +                 0.91, 0.86, 0.78, 0.71,
     +          0.40, 0.33, 0.22, 0.06,
     +                 0.91, 0.86, 0.78, 0.71,
     +                 0.15, 0.17, 0.20, 0.26, 0.39, 0.48 /
      Data  hground / 10.0 /
      Data vav / 2.5, 7.5, 15.0, 25.0 /
      Read (1,*) az
      read (1,*) cp,ts,sd, vexit,qm,qn,hstack
      read(1,*) vground, aa, ab, xb, xe, xinc, yb, ye, yinc, z
      read(1,*) cf,ct,sl
      read(1,*) sc, se
      read(1,*) ta
      read(1,*) ((fds(i,j), i=1,4), j=1,8)
      pi = 22.0/7.0

      if (aa.Eq.'A') then
        iwp = 1
        go to 10
      endif
      if (aa.Eq.'B') then
        iwp = 2
        go to 10
      endif
      if (aa.Eq.'C') then
       iwp = 3
```

```
      go to 10
     endif
    if (aa.Eq.'D') then
      iwp = 4
      go to 10
     endif
    if (aa.Eq.'E') then
      iwp = 5
     endif
    if (aa.Eq.'F') then
      iwp = 6
     endif
c
 10   if (ab.Eq.'A') then
       isp = 1
       ay = 'stability - very unstable: '
       go to 20
      endif
    if (ab.Eq.'B') then
       isp = 2
       ay = 'stability - unstable: '
       go to 20
      endif
    if (ab.Eq.'C') then
       isp = 3
       ay = 'stability - neutral: '
    endif
    if (ab.Eq.'D') then
       isp = 4
       ay = 'stability - stable: '
    endif
c
 20  if (sc.Eq.'Ys') goto 888
c
    vstack = vground * (hstack/hground)**p(iwp)
c
    qh = qm * (ts-ta) *cp
c
    if (qh.Ge.1.0E6) then
      deltah = 0.84 * (12.4 + 0.09*Hstack) * (qh**0.25)/Vstack
    else
      deltah = 3.0 * Vexit * sd/vstack
```

```
      endif
      heff = hstack + deltah
      veff = vground * (heff/hground)**p(iwp)
c
c  estimation of dispersion coefficients and conc.
c
      I = 1
      x(i) = xb
      do 100 j = xb,xe,xinc
        x(i) = j
        sigmay(i) = a(isp) * (x(i)**b(isp))
        sigmaz(i) = c(isp) * (x(i)**d(isp))
        parta = ( qn/(2*pi*veff*sigmay(i)*sigmaz(i)) )
        partb = exp( -y**2 / (2 * sigmay(i)**2) )
        partc = (exp( -(z - heff)**2 / (2 * sigmaz(i)**2) )
     +        + exp( -(z + heff)**2 / (2 * sigmaz(i)**2) ) )
        conc(i) = parta*partb*partc
        cone(i) = conc(i)*(1/(8.0**0.4))
        N = i
        I = I + 1
 100  continue
c
      xg = (heff/(c(isp)*2.4477))**(1/D(isp))
c
      partd = 0.5/D(isp)
     xmax = (((heff**2)*d(isp))/((b(isp)+d(isp))*(c(isp)**2)))**partd
c
        sigmym = a(isp) * (xmax**b(isp))
        sigmzm = c(isp) * (xmax**d(isp))
c
        parte = ( qn/(2*pi*veff*sigmym*sigmzm))
        partf = (exp(-(z - heff)**2 / (2 * sigmzm**2) )
     +        + exp( -(z + heff)**2 / (2 * sigmzm**2) ) )
     glcmax = parte*partf
     gcmaxe = glcmax*(1/(8**0.4))
c
     if(cf.Eq.'No') goto 61
c     fumigation condition(for stability of c and d)
      write (*,*) az, ay,'wind speed (m/s) ', vground
      write (*,*) 'emission rate (g/s): ', qn
      write (*,*) 'fumigation conditions'
      do 300 I = 1,n
```

```
        hf(i) = heff+(2.15*Sigmaz(i))
        sigyf(i) = sigmay(i) + (0.47*Heff)
        concf(i) = qn/(1.1*Sqrt(2*pi)*sigyf(i)*hf(i)*veff)
        confe(i) = concf(i)*(1/(8.0**0.4))
        Write (*,*) x(i), confe(i)
 300    continue
      goto 1000
 61    if (ct.Eq.'No') goto 51
c     trapping condition
       write (*,*) az, ay,'wind speed (m/s) ', vground
       write (*,*) 'emission rate (g/s):', qn
       write (*,*) 'trapping conditions'
         do 351 I = 1,n
         part1 = qn/(2*pi*veff*sigmay(i)*sigmaz(i))
         part2 = exp((-0.5*((Z-heff/sigmaz(i))**2)))
         part3 = exp((-0.5*((Z+heff/sigmaz(i))**2)))
         sum(i) = 0.0
      Do 400 m=1,3
         part4 = exp(-0.5*(Z-heff-(2*m*sl)/sigmaz(i))**2)
         part5 = exp(-0.5*(Z+heff-(2*m*sl)/sigmaz(i))**2)
         part6 = exp(-0.5*(Z-heff+(2*m*sl)/sigmaz(i))**2)
         part7 = exp(-0.5*(Z+heff+(2*m*sl)/sigmaz(i))**2)
         sum(i) = sum(i) + part4+part5+part6+part7
 400   continue
      conct(i) =(part1*(part2+part3)+sum(i))
      conte(i) = conct(i)*(1/(8.0**0.4))
      Write(*,*) x(i), conte(i)
 351   continue
      goto 1000
c     seasonal average concentrations
 888   do 601 I =1,4
      vav(i) =vav(i)*5.0/18.0
 601   Continue
      I = 1
      x(i) = xb
      do 786 j = xb,xe,xinc
       x(i) = j
       n = i
       I = I + 1
 786   continue
c
      do 602 Id =1,8
```

```
      do 603 I =1,n
        sconc(ld,i) = 0.0
        Sigmaz(i) = c(isp) * (x(i)**d(isp))
        do 604 ls =1,4
        vstack = vav(ls) * (hstack/hground)**p(iwp)
   qh = qm * (ts-ta) *cp
   if (qh.Ge.1.0E6) then
     deltah = 0.84 * (12.4 + 0.09*Hstack) * (qh**0.25)/Vstack
   else
     deltah = 3.0 * Vexit * sd/vstack
   endif
      hs(ls) = hstack + deltah
      parta1 = 8.0*Qn*fds(ls,ld)
      parta2 = (pi**1.5)*Sqrt(2)*sigmaz(i)*vav(ls)*x(i)*100.0
      Parta3 = exp((-0.5*(Hs(ls)**2))/(sigmaz(i)**2))
      sconc(ld,i) =(sconc(ld,i)+(parta1/parta2)*parta3)
      scone(ld,i) =sconc(ld,i)*(1/(8.0**0.4))
604    Continue
603    continue
602    continue
      write (*,*) az, ay,'season:  ',se
      write (*,*) 'emission rate (g/s):', qn
      write (*,963)
963    format (3x,9x,'w',7x,'sw',8x,'s',8x,'se',7x,'e',8x,'ne',8x,
  +          'n',7x,'nw')
      do 111 I =1,n
      write (*,1) x(i) , (scone(ld,i), ld = 1,8)
1      format (1x,f6.0,8E9.2)
111    Continue
      goto 1000
51     write(*,*) az,ay,'wind speed (m/s)', vground
      write (*,*) 'emission rate (g/s):', qn
       do 200 I = 1, n
         write(*,*) x(i), cone(i)
200     continue
      write(*,*)
      write(*,*) 'distance plume touches ground (metres):',xg
      write(*,*) 'distance where maxm glc occurs (metres):',xmax
      write(*,*) 'maximum ground level conc. (Grams/m3):', gcmaxe
      write(*,*) 'plume rise (metres):', deltah
1000  stop
      end
```

Line source

```
c     p :      wind profile coefficents (unstable,neutral,stable)
c     q :      emission in gm/mt/hr
c     ef :     emission factors in gm/mt/veh (light duty gasoline
c              light duty diesel, heavy duty diesel, two wheelers
c              three wheelers)
c     vehd :   vehicle density (numbers/hour)
c     a, b, c, alpha, beta, gamma : dispersion parameters
c      aa :    character variable defining stability
c     wc0, wc1 : wind velocity correction factors
c     ws45, ws10 : ambient wind speed at 4.5 Mts & 10 mts
c     theta, thetar : angle between the road and wind in anti-
c                     clockwise direction in degrees & radians
c     temp :  ambient temperature in kelvin
c     sht :   source height in mts
c     xb, xe, xinc/: coordinates perpendicular to the road and
c     zb, ze, zinc : above the ground ..Begin, end, increment
c     bflux : buoyancy flux
c     pch :   plume centre height in mt
c     sigmaz : dispersion coefficent in vertical direction im mts
c     conc & cone : concentration in micro.Gms/mt^3 1 hr & 8hr avg
c
      dimension p(3),a(3), b(3), c(3), beta(3),
     + alpha(3), gamma(3),wc0(3),wc1(3), sigmaz(100), x(100),
     + z(100,10), conc(100,10),pch(100), cone(100,10)
      real ws10,theta,temp,sht
      integer xb,xe,xinc,zb,ze,zinc
      character aa*1, ab*6, ac*3
      open(2,file ='chary.Dat',status='old')
      data a, b, c, alpha, beta, gamma, wc1, wc0, p/
     + 1.49, 1.14, 1.14,
     + 0.15, 0.10, 0.05,
     + 0.77, 0.97, 1.33,
     + 20.7, 11.10, 11.10,
     + 5.82, 3.46, 3.46,
     + 3.57, 3.50, 3.50,
     + 0.18, 0.27, 0.27,
     + 0.23, 0.38, 0.63,
     + 0.45, 0.23, 0.16/
      Read(2,*) aa,ab,ac
      write (*,*) 'stability:', aa
      write (*,*) 'link no :', ab
```

```
      write (*,*) 'pollutant:', ac
      read(2,*) q
      write(*,*) 'emission rate (gms/mt/hr):', q
      read(2,*) ws10,theta,temp,sht
      write(*,*) 'wind speed:', ws10
      read(2,*) xb,xe,xinc,zb,ze,zinc
      pi = 22.0/7.0
      Thetar =  theta*0.0174532
      If(aa.Eq.'A') then
      isp=1
      goto 20
      endif
      if (aa.Eq.'B') then
      isp=2
      goto 20
      endif
      if (aa.Eq.'C') then
      isp=3
      endif
20    ws45 =ws10*(5.0/18.0)*(4.5/10.0)**P(isp)
      we = ws45*sin(thetar)+wc0(isp)
      wb = ws45*sin(thetar)+wc1(isp)
      f = 1.0+Beta(isp)*((abs((theta-90.0)/90.0))**Gamma(isp))
c     plume rise,dispersion coeff,concentration
      bflux =0.01184*Veh/temp
      i= 1
      ii=1
      do 30 j =xb,xe,xinc
      x(i) =j
      ii=1
      do 40 k=zb,ze,zinc
      z(i,ii) =k
      pch(i)=sht+sqrt(bflux/(alpha(isp)*wb**3))*x(i)
      sigmaz(i) =(a(isp)+(b(isp)*f*x(i)))**c(isp)
      part1 = q/(3600*(sqrt(2*pi)*sigmaz(i)*we))
      part2 =0.5*(Abs((z(i,ii)+pch(i))/sigmaz(i)))**2
      part3 =0.5*(Abs((z(i,ii)-pch(i))/sigmaz(i)))**2
      part4=exp(-part2)
      part5=exp(-part3)
      texp =part4+part5
      conc(i,ii) =part1*texp*10e+6
      cone(i,ii) =conc(i,ii)*(1/(8**0.4))
```

```
      Nn=ii
      ii=ii+1
40    continue
       n=i
      i=i+1
30    continue
      write (*,303)  (z(1,ii) , ii=1,nn)
303   format(//11x, 7(f3.0,6X)/)
      do 50 i=1,n
      write (*,404)  x(i),(conc(i,ii), ii=1,nn)
404   format(3x, f5.0, 3X, 7(f7.2,2X))
50      continue
       write (*,304)  (z(1,ii) , ii=1,nn)
304   format(//11x, 7(f3.0,6X)/)
      do 51 i=1,n
      write (*,405)  x(i),(cone(i,ii), ii=1,nn)
405   format(3x, f5.0, 3X, 7(f7.2,2X))
51      continue
365     stop
        end
```

Area source

```
c      p :      wind profile coefficents
                (unstable,neutral,stable)
c     q(0)  :  emission rate in  g/mt^2-sec of the receptor grid
c     q(i)  :  emission rate in  g/mt^2-sec of the upwind grid
c     aa    :  character variable defining stability
c     ws55, ws10  : ambient wind speed at 5.5Mts (avg human ht)&10 mts
c     conc & cone : concentration in micro.Gms/mt^3 1 hr & 8hr avg
c      x :      grid distance in mts

      dimension p(3), a(3), b(3), q(5), partb(5)
      character aa*10, ab*2, ad*3
      open(2,file ='area.Dat',status='old')
      data a, b, p/
     + 0.4,  0.15, 0.06,
     + 0.91, 0.75, 0.71,
     + 0.16, 0.23, 0.45/
      Read(2,*) aa, ab, ad
      write (*,*) 'stability:', aa
      write (*,*) 'grid no.:',  Ab
      write (*,*) 'pollutant:', ad
      do 45 I = 1,5
      read(2,*) q(i)
 45   continue
      write(*,*) 'emi rate in receptor grid(migms/mt2-sec):', q(1)
      write(*,*) 'emission rate (gms/mt2-sec):', q(2)
      write(*,*) 'emission rate (gms/mt2-sec):', q(3)
      write(*,*) 'emission rate (gms/mt2-sec):', q(4)
      write(*,*) 'emission rate (gms/mt2-sec):', q(5)
      read(2,*) ws10, x
      write(*,*) 'wind speed (mt/sec):', ws10
      write(*,*) 'grid side (mts):', x
      pi = 22.0/7.0
      If(aa.Eq.'Unstable') then
      isp=1
      goto 20
      endif
      if (aa.Eq.'Neutral') then
      isp=2
      goto 20
      endif
      if (aa.Eq.'Stable') then
```

```
      isp=3
      endif
20    ws55 =ws10*(5.0/18.0)*(5.5/10.0)**P(isp)

c     concentrations

      parta=sqrt(2/pi)*(((x/2)**(1-b(isp)))/(ws55*a(isp)*(1-b(i))))
      sum  = 0.0
      Do 25 I = 2,5
      partb(i) = q(i)*(((2*i+1)**(1-b(isp)))-((2*i-1)**(1-b(isp))))
      sum  = sum + partb(i)
25    continue
      conc = parta * (q(1) + sum)
      write(*,*) 'concentration (mg/mt^3):', conc
      stop
      end
```

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